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METHODS FOR SEPARATION OF SEDIMENT FROM STORM WATER AT CONSTRUCTION SITES

by

J.F. Ripken, J.M. Killen,
and
J.S. Gulliver

St. Anthony Falls Hydraulic Laboratory
University of Minnesota
Minneapolis, Minnesota 55414

Grant No. R803579

Project Officer

Richard P. Traver
Storm and Combined Sewer Section
Municipal Environmental Research Laboratory (Cincinnati)
Edison, New Jersey 08817

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problems.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and search for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The need exists to develop technology and methods for the protection of our receiving waters from soil sediment erosion. A specific area in which pollutional abatement practices and techniques can be feasibly and practicably applied are at construction site operations. This report presents a review of published technical literature from American manufacturers of solids removal equipment.

Francis T. Mayo
Director
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This report is submitted by the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota in partial fulfillment of Grant No. R803579.

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SECTION A

INTRODUCTION

During the construction of housing developments, shopping centers, highways, airports, and various other large projects, it is frequently necessary to remove vegetative cover and to expose unprotected soils. These exposed soils are readily subject to severe erosive action by falling raindrops and the subsequent rainstorm runoff during the construction period. The eroded material then becomes a polluting and potentially damaging load in the adjacent drainage streams into which the runoff normally flows. Any attempt to reduce this damaging occurrence involves a two-fold approach: (1) the development of construction practices to reduce the initial erosion and (2) the introduction of practical sediment control devices to intercept and remove the unwanted solids from the runoff water before the water leaves the construction site. This report is concerned with the second approach.

Any attempt to remove unwanted solids must first categorize the detrimental nature of the solids. A Task Committee report of the American Society of Civil Engineers [A-1]* says that the coarse grained sediments are the damaging part in terms of deposition in downstream channels, reservoirs, highways, or urban and agricultural areas. Other groups or agencies may utilize other standards of damage or pollution which may rule against even very fine solids in very dilute concentrations. The ultimate selected size of solid removal will therefore depend on the standards considered applicable to a particular construction site.

Because erodible materials at construction sites may range from coarse gravel to fine clay, the methods of separation or removal must accommodate this range. It is intuitively apparent that the larger particles may be readily trapped in small and relatively low cost debris basins on-site. The more difficult removal relates to the finer silts and clays, and this report is primarily concerned with reviewing the methods which might be employed to affect this removal.

This study will make the assumption that the eroded materials are largely mineral solids and that removal of organic solids is not a primary concern. It is also assumed that significant amounts of both mineral and organic solids were normally removed from the construction site in natural runoff processes prior to construction operations. Stall's findings, [A-2], indicate that in most areas of the mainland United States, the normal sediment yield is between 3 and 4 tons per acre per year except in the southeast where rates are 7 to 10 tons.[**] This prior ambient condition should be locally evaluated and allowed for in establishing the responsibility of the construction contractor to clarify construction site runoff. Establishing the solids removal, which is the reponsibility of the contractor, is part of the total problem.

---

*Numbers in brackets relate to the List of References at the end of the Section.

In order to establish the expected load of fines to be processed, it has been considered necessary to include a brief initial discussion of (1) the probable runoff and resulting total sediment load delivered by the construction site and (2) the probable influence that simple settling basins might have in establishing the sediment load in the discharge from the basin.

Separation of solids from water is an old problem which has been subjected to extensive development resulting in a wide variety of proven and commercially available hardware components. In consequence, this study, based on review of literature, does not contemplate the development of new components, but intends instead to provide understanding leading to a proper selection and matching of available components to form an effective, least cost system to fit the special needs of the problem.

LIST OF REFERENCES

[A-1] American Society of Civil Engineers, "Sediment Control Methods," Task Committee Report, Journal of Hydraulic Division, Proceedings, ASCE, March 1969, p. 660.

[A-2] Stall, J.B., "Man's Role in Affecting Sedimentation of Streams and Reservoirs," Proceedings, Second Annual Conference, American Water Resources Association, 1966, pp. 79-95.

[**] The units of measure used throughout this report are those employed in the published literature and catalogs which served as a reference source. Since current practice still employs these units no attempt has been made to offer SI equivalent units.

SECTION B

SIGNIFICANT PROPERTIES OF THE SUSPENDED SOLIDS AND THE CONVEYING WATER

The selection of solid separating devices and operating procedures is in many cases critically dependent on certain properties of the particular water and solids being dealt with. The most significant properties, the range of probable values, and the methods of evaluation of these properties are briefly discussed in the following paragraphs.

THE SOLIDS

Processes used to separate a suspension of soil solids from water usually employ interception, mass-attractive forces, or electrochemical forces. With all of these methods, effective high rates of separation may be critically dependent on the relative weight, size, and concentration of the solid particles in the water, and these must be suitably evaluated.

The relative weight of the soil solids is most commonly expressed in specific gravity, which is easily determined for a representative sample by weight measurements in dry and submerged states. The specific gravity of most soil solids is about 2.65.

The grain size of the silt-clay solids of primary interest is too small to be determined by mechanical sieving and is usually determined by time interval readings of a special hydrometer floating in a water suspension of the sample. The procedure is simple but time consuming. The hydrometer readings measure the average density of the suspension during the course of a sedimentation process. From previous calibrations based on the Stoke's law, the timed readings from the hydrometer can be used to infer the size distribution of the solid particles. Typical size analysis curves are shown later in Fig. M-1.

Test procedures for the determination of both the specific gravity and hydrometric size distribution are given in standards published by the American Society for Testing and Materials.

The concentration of the solids in the water is an important factor in establishing the process load that will be imposed on the separation system or its individual components. Concentration values for these considerations are usually expressed in weight units of milligrams per liter (mg/l) or parts per million (ppm).

Larger values of concentration (in excess of 100,000 mg/l) may be measured by weighing the representative sample wet and dried.

The terms "suspended solids" and "turbidity" are sometimes confused. "Suspended solids" are measured by gravimetric methods, while "turbidity" is measured as an optical manifestation of the presence of the "suspended solids" in the water. "Turbidity" is a lack of clarity in a water and also should not be confused with color. Color may be either light or dark, with the clarity not necessarily impaired.

Smaller values of concentration (less than 5,000 ppm) may be approximated by a procedure in which a simple grab sample in a suitable glass container is introduced into an optical light beam. The optical properties of the suspension can be measured as transmitted, reflected, or refracted light values from which the concentration may be inferred using prior calibrations. A substantial amount of development work has gone into these so-called turbidimeters or nephelometers. No wholly satisfactory instrument is widely accepted as a standard. A simple but frequently accepted older form of instrument suitable for this measurement is the Jackson turbidimeter. In this, a standard vertical glass tube with a standard light below its base is progressively filled with the test fluid until the light, viewed through the fluid surface, is extinguished. The measure of extinguishing depth can be read either in millimeters or on an alternate concentration scale reading in parts per million. This scale is based on an extinguishing calibration with a standard powdered silica. The common standard tube reads to 25 centimeters of depth or a silica range from 100 to 5,000 ppm. A second tube of 75 cm in length provides greater sensitivity and reads down to 25 ppm. Values read on the calibrated scale are known as Jackson Turbidity Units or JTU. The Jackson meter is made and used in accordance with the American Public Health Association, Standard Methods for the Examination of Water or Wastewater, 13th Edition (1971).

THE WATER

The most significant properties of the conveying water in relation to the separation of solids are the viscosity and the hydrogen ion concentration as measured by the pH value. All separation processes which extract the solid from the water necessitate a relative motion between the solid and the water, thus generating viscous shearing forces which resist or slow the relative motion. Since water viscosity almost halves in the temperature range of natural waters (0° to 30°C) temperature can have a substantial effect on the separation rates of most processes. For analytical purposes, viscosity is determined by simple temperature measurements using standard tabular values.

Suspended soil solids of diameter larger than about 0.2 micron may be induced to move against viscous resistance by the application of an external force such as gravity. However, solids of a size smaller than this may remain indefinitely in stable suspension in a gravitational field because of the more dominant influence of internal electro-chemical forces. The latter forces may be greatly diminished by several factors and a very important and controllable factor is the hydrogen ion concentration of the water as measured by its pH value. pH values for a water sample may be directly read using a wide variety of specialized electrical meters or very simply by color comparison evaluations using especially treated paper tapes.

SECTION C

RUNOFF HYDROLOGY OF THE CONSTRUCTION SITE AND THE SEDIMENT LOAD

RUNOFF VALUES

The selection of cost-acceptable procedures or facilities to remove objectionable solids from construction site runoff is critically dependent on establishing the quantity of water which will run off and the quantity of solids that the runoff will contain. Under runoff conditions prior to construction, a given site would provide a certain water and solids yield. It is presumed that the construction contractor is legally responsible for the removal of only those added solids which are a consequence of his construction activity. Quantity considerations must also recognize that a detention basin or other solids removal facilities must process all of the runoff from all of the watershed upstream of the point of detention. It is, therefore, in the contractor's interest to select his drainage and collection layout to minimize the handling of water which does not originate from his area of responsibility.

The most important carrier of soil solids is surface runoff originating as rain or snowmelt. Rain is by far the most significant in terms of load considerations. Soil movement also occurs as a consequence of wind action, but on most sites this is not a significant factor within the life span of a construction operation.

The removal of precipitation from the construction site by evaporation, transpiration, or percolation into the groundwater will not transport soil solids. These on-site processes of water removal should be enhanced where practical, but in most situations this is not feasible to any great extent. In consequence, the origin of a runoff estimate for designing solids removal facilities must begin with rainfall data. Rainfall data originates in the historic records of the U.S. Weather Bureau. These data are available in a variety of forms. The most useful of these forms for the current purpose are the mean annual total precipitation taken from Ref. [C-1] and shown in Fig. C-1, and the 24-hour storm taken from Ref. [C-2] and shown in Fig. C-2.

It should be noted in Fig. C-1 that within the continental United States (and Alaska) average annual rainfalls may range up to 96 inches. If Hawaii is included, this range extends to 200 inches. On the low side, values of less than 4 inches may be expected in Nevada.

Short term rainfall as great as 45 inches in 72 hours has been measured in Florida. Design for such large short-term extremes cannot be economically justified and therefore "calculated risk" designs based on averages must be employed. For many design purposes the rainfall that occurs in 24 hours constitutes a reasonably heavy storm for a region, and data have been assembled in Fig. C-2. Values shown range from 1-1/2 to over 8 inches.

The data for Fig. C-2 relate to a storm with a return period of 5 years. The data for longer periods of return are also available. However, for the shallow debris basins under consideration, the risk of major damage or loss of life are probably not involved even with storms having a period materially greater than 5 years. Oscanyan [C-3] suggests a 10-year recurrence value for designing a basin spillway. It must also be recognized that a debris basin providing for a 5-year storm return period will materially reduce the downstream flood peak even for storms of greater period. While a basin for a 5-year storm may overload and spill fines for these larger storms, it should still serve to capture the more damaging solids which are those larger than a medium sand.

Not all of the precipitation which falls on a given construction site appears as surface runoff. A time vs. discharge hydrograph of the actual runoff would be most useful for designing a solids removal facility, but unfortunately site data will rarely directly provide this. In consequence, the desired data must be synthesized using related information. Considerable recent attention has been given to this problem, [C-4], but current practice, [C-5], still employs a relatively simple rational formula given as:

$$R = KP$$

where R = direct runoff in selected time span in inches per acre

K = runoff coefficient depending on surface and antecedant conditions

P = average precipitation in time span in inches.

The value of K for urban residential areas is given as 0.3 for single houses and 0.5 for garden apartments; 0.9 for commercial and industrial areas; 0.05 to 0.2 for forested areas, depending on soil; 0.05 to 0.3 for park farm land and pasture; and 0.85 for pavement. For areas disturbed by construction activities, the runoff may vary widely with the nature of the exposed material. Runoff over deep gravel areas may be virtually zero, whereas clay and other impervious soils may yield virtually complete runoff.

The volume of a debris basin for runoff could be based on a wide variety of combinations of a debris basin with an auxiliary solids removal facility. On the one extreme, a debris basin could be provided to capture the entire annual runoff and controlled to permit discharge at a low-level mean annual rate. Detention time in such a large reservoir would inherently provide a high level of gravity clarification and probably no need for effluent treatment facilities. The space and capital investment in the basin would, however, be substantial. On the other extreme, the debris basin could be eliminated and all of the runoff could be processed directly through high-rate solids removal facilities. Since such facilities are fairly expensive to capitilize per unit of volume processed, any attempt to provide facilities to meet peak flows would be excessively costly. A basin volume based on pertinent practical values derived from the foregoing rational formula is believed to be a useful point of beginning in examining a combined system.

Some approximation for the extent of the basin may be obtained by assuming for a mean condition that a 24-hour, 5-year storm delivers 4 inches of precipitation on a surface having an average K value of 0.5. If the average depth of the debris basin is assumed as 5 feet, the area of the basin would be about 3 percent of the area of the watershed for holding the 24-hour storm.

It is not the objective of this study to pursue the design of debris basins other than to roughly predict the approximate water and sediment load that will be discharged from the basin for subsequent treatment. For those readers who are interested in the basin design proper, reference should be made to [C-3] and [C-6].

The effluent rate of flow from a debris basin depends on the design detention time. Figure C-3 from Pennel [C-6] indicates that a settling basin with a maximum depth of 10 feet will achieve fairly complete settling of all materials except clay after about three days. It appears that there is little point in providing detention beyond five days, and that retrenching to two days would not significantly affect most sediment removal values within a basin. There is some merit in minimizing the design detention time in order to minimize the influence of closely following storm events. However, a basin drainage time of more than two days should be considered in light of the way in which it contributes to a reduction in the rate of effluent flow and consequently in the required capacity of the solids-removing auxiliary facility. If the basin were to be provided with a low level pipe type outlet which is sized to complete the drainage within one day following the 24-hour storm, the amount of effluent water for the average conditions supposed above would be approximately $43560(4 \times 0.5)/12 = 7260$ cubic feet/day/acre of watershed. This reduces to 0.084 cfs/acre or 38 gpm/acre. These discharge values will increase directly with the acres involved in a construction watershed and inversely with the number of days selected for controlled drainage of a basin. Further reduction of runoff by increasing the on-surface water retention, erosion control procedures, and collection of storm water only from disturbed areas could significantly reduce water processing requirements. While these considerations of the magnitude of the rate of effluent do not sharply define a design value, they do give insight into the major factors and trade-offs involved in a design selection.

In the foregoing consideration of basin volume no mention was made of volume requirements for solids storage. Since the basin is expected to have a normal service life of only a few seasons, and since it may normally be drained dry between storms and be observable, it is presumed that the construction contractor will take such steps as may be necessary to remove collected settlements that may interfere with future settling operations. If this is not to be the case, then sediment storage volume for the entire construction period should be provided as discussed in Section D which follows.

THE SEDIMENT LOAD

The Soil Conservation Service has had a long standing need for estimating soil loss by erosion from agricultural land. They have developed a "Universal Soil Loss" equation for this purpose. It is proposed that disturbance of land for construction purposes has much in common with the tillage of land for agricultural purposes. Methods for soil loss calculation may be borrowed from this source for estimation of soil loss from construction sites. Complete analogy cannot be established, however. Construction disturbances are of much greater depth than agricultural tillage. The universal soil loss equation seems to be verified on an annual average; its use to determine short term loss from a single storm may be very rough.

The universal soil loss equation is as follows:

$$E = RKLSCP$$

where E = Total sediment loss in tons/year/acre

R = Rainfall factor (see Fig. C-4)

K = Erodibility factor

LS = Slope length factor

C = Vegetative cover factor

P = Erosion control procedure factor.

Since it would not be reasonable to set a limit of extreme conditions as occurring simultaneously with all factors, single condition will be chosen in an example as a representative condition to give some sense of the problem magnitude.

The rainfall factor "R" is available in Ref. [C-7] and included here in Fig. C-4. This factor can be seen to range from 15 to 350 over the eastern United States. Factors have not been worked out for the western United States. A value of 350 is considered a maximum value for the continental United States [C-7].

The soil erodibility factor depends on the nature of the soil. An average of 0.35 will be used for crop land to 0.75 for a construction site.

The slope length factor depends on the topography. It will be arbitrarily set to 0.35 for comparative purposes.

The vegetative cover factor can typically vary from 0.012 for short brush, to 0.43 for cultivated land, and to 1 for a disturbed construction site [C-7].

The erosion control factor $P = 1$ will be assumed since the problem estimated is before erosion control.

The variation of soil loss per unit area from a construction site then conservatively ranges from

$$15 \times .75 \times .35 \times 1 \times 1 \approx 4 \text{ tons per acre per year to}$$

$$350 \times .75 \times .35 \times 1 \times 1 \approx 92 \text{ tons per acre per year.}$$

If the construction site was formerly cultivated crop land, there could have been an estimated soil loss of

$$15 \times .35 \times .35 \times .43 \times 1 \approx 3/4 \text{ tons per acre per year to}$$

$$350 \times .35 \times .35 \times .43 \times 1 \approx 20 \text{ tons per acre per year.}$$

No data was available for urban land, but the above loss estimate might be good for urban land well covered with buildings, streets, parking lots, well cared for lawns, etc.

The particle size distribution of the soil loss material will depend on the type of soil exposed to runoff. Particles larger than 5 mm probably will not be transported. Particles larger than 0.05 millimeters (larger than silt size) are very easily trapped in a small debris basin. Examination of Fig. C-3 will show, however, that to trap sizes smaller than 0.05 will require increasingly larger and more carefully designed debris basins. The flow through the basin must allow time for the particles to settle to the bottom. This can be accomplished by having a sufficient basin volume and a basin shape which will reduce the settling distance and increase the retention time. Careful design of inlet and outlet structures is required to reduce unwanted liquid currents which would cause "short circuiting." Addition of baffles to suppress secondary currents may be necessary.

Figure C-3 suggests that the trapping of clay sizes in a debris basin requires an unusually large basin volume and/or supplementary means of solids removal such as flocculation, mechanical filtering, or some combination of these and other methods.

If the soils in the above sample calculations were to contain up to 25 percent of materials less than 0.0025 mm (clay) (see for example Fig. M-1), then 1 to 23 tons of fine solids per acre per year would require removal by auxiliary separation facilities. This would amount to 5.5 to 125 pounds per day per acre while processing 160 to 550 cubic ft of water per day per acre. The above assumed maximum erosion occurs in maximum average rainfall areas. The concentration would vary from 550 mg/l to 3640 mg/liter.

Because the amount of very fine material carried from a construction site by runoff can vary greatly depending upon the nature of the soil and erosion control practices, a specific careful estimate of soil loss must be carried out for each site based on soil samples, rainfall factors, topography, and erosion control procedures. The necessity of special equipment for removal of fines must be based on established guidelines such as those given in [C-8] for fine material tolerance in construction site runoff. It is conceivable in some cases that adequate "clearing" of discharge water can be achieved in a specially designed debris basin, particularly in porous soil and light rainfall areas.

A summary of various methods that may be used to reduce or control on-site erosion for construction activities is contained in Refs. [C-9] and [C-10].

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[C-9] Hotes, F.L., Ateshian, K.H., and Sheikh, B., Comparative Costs of Erosion Control Construction Activities, Environmental Protection Agency, EPA 430/9-73-016, July 1973.

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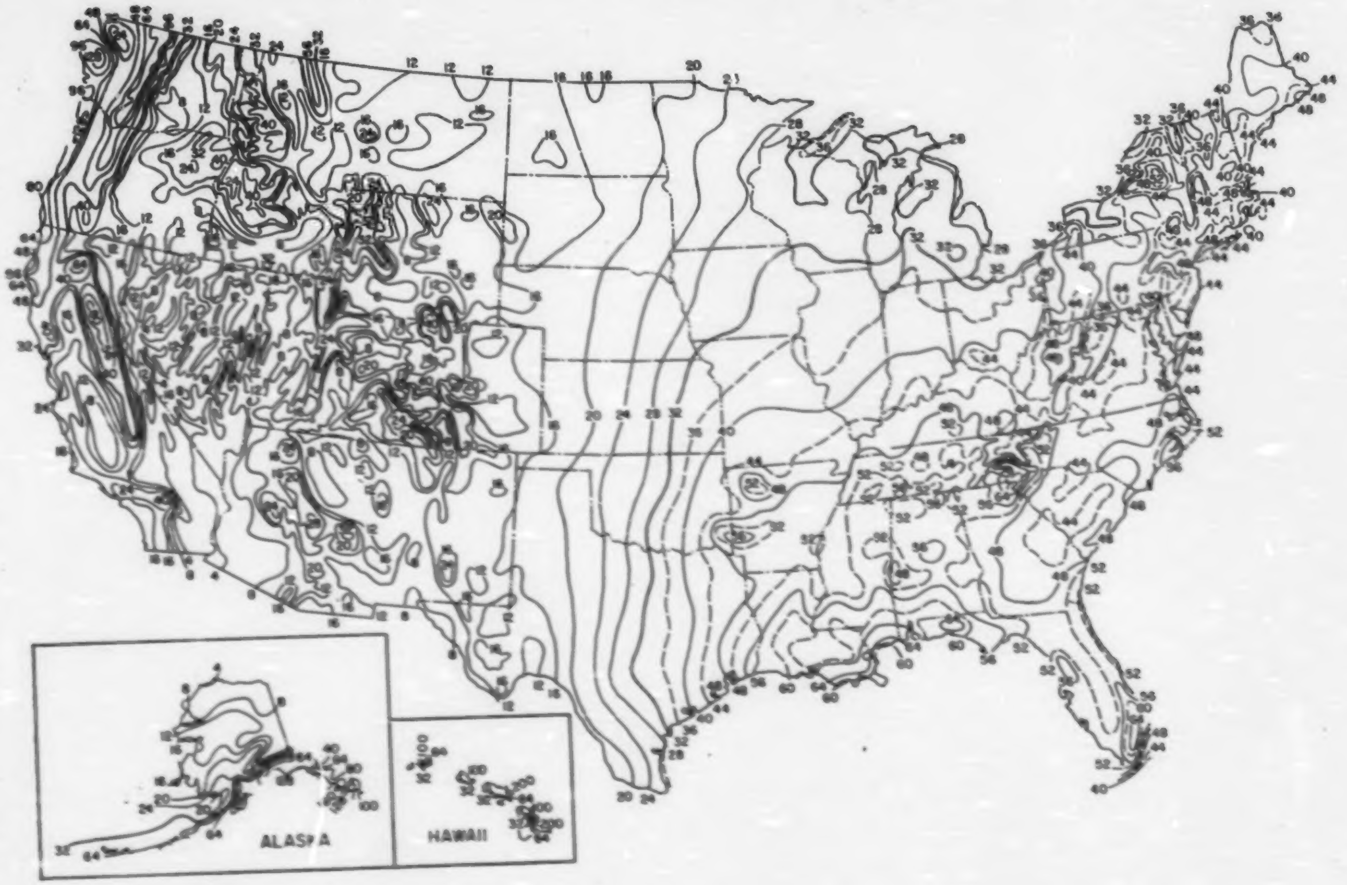
ALASKA
HAWAII

Fig. C-1. Mean annual total precipitation in the United States (in inches). (U.S. Weather Bureau) (From Ref. [C-1])

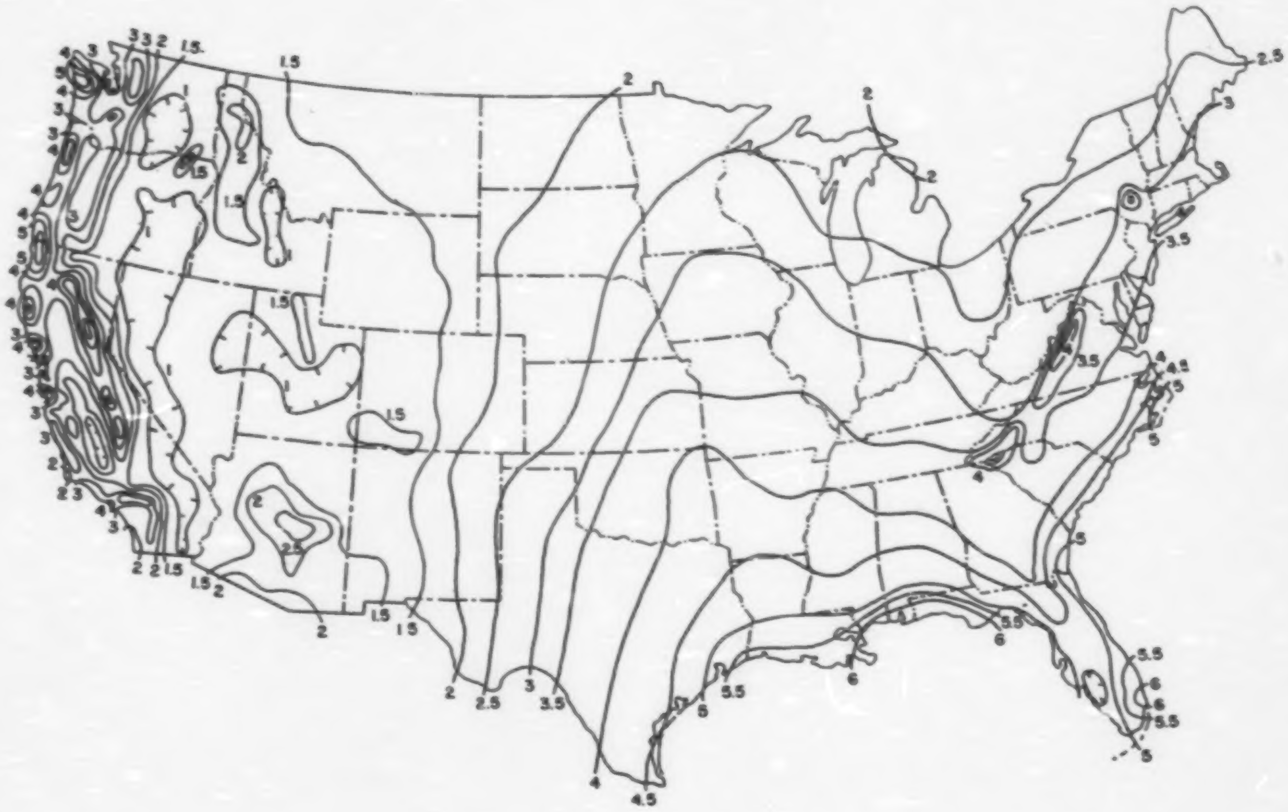
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
1

Fig. C-2. Maximum probable rainfall in 24 hours for a return period of 5 years (From Ref. [C-1])

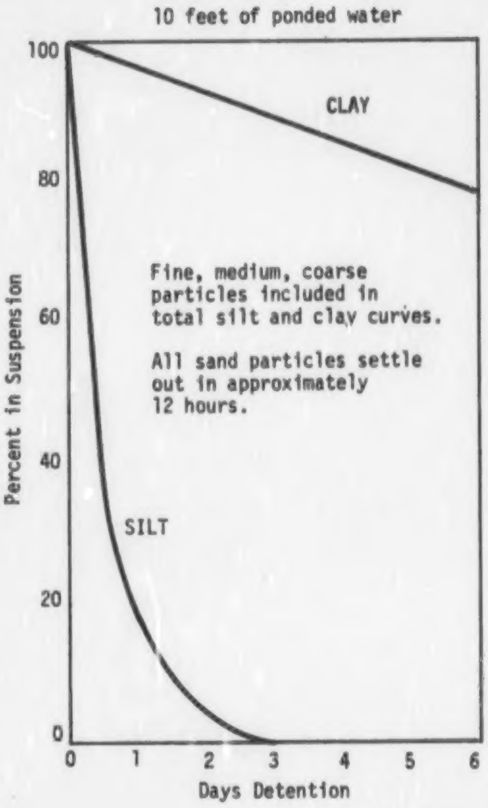

Fig. C-3. Percent of soil particles remaining in suspension (From Ref. [C-6])

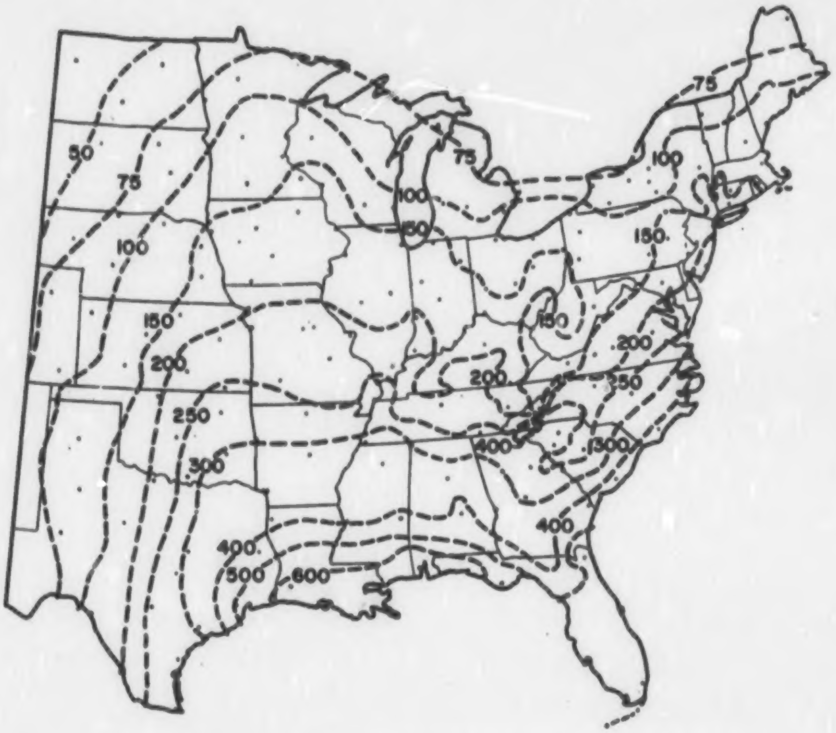
75
50
75
75
100
100
150
100
150
150
150
200
200
200
250
250
300
400
300
400
400
500
600

Fig. C-4. Values for rainfall factor R (From Ref. [C-7])

SECTION D

THE STORAGE RESERVOIR AND SETTLING BASIN

A storm water storage reservoir can be used for storage of eroded material, as a trapping device for the removal of sediment, and as storage for the total runoff until processing for suspended-material-removal can be carried out. Each successive use requires a greater volume. Use for either sediment or water storage imposes only volume constants for the reservoir; however, use as a sediment trap imposes requirements on shape to maximize trapping efficiency.

An estimate of the expected sediment discharge as calculated by the procedure outlined previously (or an effective alternative) and establishing the frequency of reservoir "clean out" will permit assigning a volume requirement for the storage of sediment. The use of the reservoir as a storage of peak storm flow can be based on peak rainfall in a given span of years. The total volume is then the sum of these two constituent volumes.

It is evident that a requirement for trap efficiency of 100 percent, obtained by holding all of the annual runoff from a construction site, would in many cases necessitate an excessively large basin. The construction of a large basin in itself would be a source of erosion, where no material holding area was available. However, an examination of Fig. D-1 will show, for example, if a trap efficiency of 85 percent were acceptable the basin size could be reduced to 1/5 of that required for 100 percent efficiency. The unfortunate consequence is that almost all of the debris passed with the 85 percent efficiency would be the very fine material including clays, organic matter, and color producing material. These fines, if discharged into a waterway, degrade its esthetic and other quality values.

Reference [D-1] and Fig. D-1 therefrom gives a summary curve for trap efficiencies of reservoirs based on the ratio of reservoir capacity to annual inflow of water. Trap efficiency is defined by the ratio of the amount that will remain in the reservoir to the amount of the sediment that is delivered to the reservoir. As would be expected, if no outflow from the reservoir occurs, the efficiency would be 100 percent.

The comments above are based on volume consideration only as they have been observed to occur in a number of large reservoirs. The sediment trapping efficiency of a reservoir can be much enhanced by adopting the principles of water treatment plant design as given in Ref. [D-2].

Discussion of design can begin with an ideal gravity sedimentation basin in which the smallest settlable particles can settle out of the flow pathway through the basin. In water supply treatment systems continuous flow systems appear to be almost exclusively preferred over a detention mode of operation. The use of the detention fill empty cycle [C-6] is probably to be preferred in this application. A number of design refinements will assist in increasing the trap efficiency. A rectangular form can be adopted in which sufficient cross section is provided to give a flow velocity of considerably less than the fall velocity of the smallest particle. Some concept of the velocities involved may be sensed from Table D-1.

TABLE D-1 (FROM REF. [D-3]). TIME AT WHICH PARTICLES WILL SUBSIDE IN STILL WATER AT 50°F
(Specific Gravity = 2.65)

Diameter of particle in mm.	Order of magnitude	Time required to settle 1 foot
10.0	Gravel	0.3 seconds
1.0	Coarse sand	3 seconds
0.1	Fine sand	38 seconds
0.01	Silt	33 minutes
0.001	Bacteria	35 hours
0.0001	Clay particles	230 days
0.00001	Colloidal particles	63 years

The basin length should be sufficient so that the detention time is sufficient for the particles to fall to the bottom. Shallow depths are preferred so that density currents are minimized. The inlet must be sufficiently baffled so that jets from the inflow do not carry across the basin, thus short circuiting the system. Baffles should be strategically placed in the basin to reduce unwanted water currents. The use of a weir as an outlet structure appears to be the most favorable form. This weir should be as long as possible (as might be achieved by folding), so that the flow toward the weir provides a fall time sufficient to trap the smallest particle possible. Clear liquid is in effect decanted off the surface. A coagulant or flocculating agent is needed to remove the very finest particles if only a sediment basin is to be used and no secondary treatment is intended. The addition of coagulants in the basin poses several problems if a simple unattended basin is to be operated effectively.

A better alternate for a fill and empty type of detention basin is to provide the largest practical simple reservoir for removal of as much of the solids as possible and to accompany this with automated and unattended separation equipment for reduction of the remaining effluent solids. The selection of suitable equipment can permit the effluent quality to be improved to any level considered necessary for eventual discharge.

Reference [C-6] was a computer study to determine the optimum size of basin for use in the Minneapolis-St. Paul area. The basin was to be operated on the fill and empty cycle. Basin volume and depth, to a limited extent, were examined. The computer program showed a maximum trap efficiency with a 4-day runoff storage and a minimum depth of 8 feet. Figure C-3 from Ref. [C-6] showed that even after four days 80 percent of the clay would still be in suspension and would normally be discharged into some watercourse.

The concern with these fine materials is the object of this study. It is evident from even the meager data presented here that even very large sediment basins cannot practically trap all of the fines, and secondary processing must be employed to separate out the clays and organic matter and remove the color, if this is considered necessary.

In addition to the foregoing, it may be informative to review here some additional assumptions and recommendations for the debris basin as given in Ref. [C-3]. These are:

1. Basin design should seek to settle out at least 70 percent of the weight of the solids in the inflow.
2. Soil samples taken from the site should be subjected to size analysis and the sizes involved for 70 percent removal should be established.
3. If soils have clay or silt content in excess of 35 percent, the trapping efficiency of a debris basin will be poor and on-site remedies may be more practical than basins. On-site remedies should also be used if total effluent flow is less than 5 cfs.
4. If site soils are unsuitable for safe embankments, it may be wise to abandon the use of debris basins for separation.
5. If design conditions indicate basins of unacceptable cost, trapping efficiency may have to be reduced below 70 percent with progressively coarser sizes being passed through.
6. The effluent discharge from a settling basin should not exceed about 250 cfs. If design studies yield more than this, multiple basins should be used. Local legal requirements for impoundments should be investigated.
7. Based on Soil Conservation Service findings, computations may be made for the peak inflow, peak outflow, surface area, settling volume, solid storage volume, basin length, and basin width.
8. A preferred basin configuration is shown in Fig. D-2.

It should be pointed out that many of the functions of a settling basin and subsequent clarification processes may be combined in a device known as a clarifier. These have been used extensively in raw water treatment plants and inherently include coagulant mixing, flocculation, and sedimentation. High rate forms of clarifiers operate at rates of 1.0 to 1.5 gpm per square foot of effective plan area. They are accordingly large and factory assembled sizes of rectangular form are transportable by road only up to about 150 gpm capacity (Fig. D-3). Capacities greater than this are generally shaped as vertical cylindrical tanks and are essentially permanently installed field assemblies. Figure D-4 illustrates the nature of the cylindrical clarifier and the relative capacity and dimensions involved.

Commerical forms of clarifiers offer full control of effluent quality, but with size, cost, and operational needs which appear unacceptable for the conditions which relate to the construction site runoff problem. It appears better to construct a simple primary debris basin as shown in Fig. D-2 using the generally available construction and excavation equipment and then concentrate on finding compact and simple commercial components to provide the necessary secondary treatment. An on-site simple earth embankment debris basin can probably be constructed with less cost and greater flexibility than a commercial clarifier. The basin has the added advantage of providing substantial storage with attendant benefits of reducing the peak rate of effluent flow and subsequent treatment capacity requirements. This use of storage to minimize the required capacity of high cost auxiliary equipment should be studied further. Consideration should also be given to automatically controlling the auxiliary treatment so as to begin withdrawal from the basin at the earliest practical time in the fill cycle. Operation should probably continue through the filling cycle, through the overflow cycle (if any), and through the emptying cycle. Operating energy requirements are a significant cost factor in many auxiliaries, but the operating costs per year are small relative to the investment in capacity.

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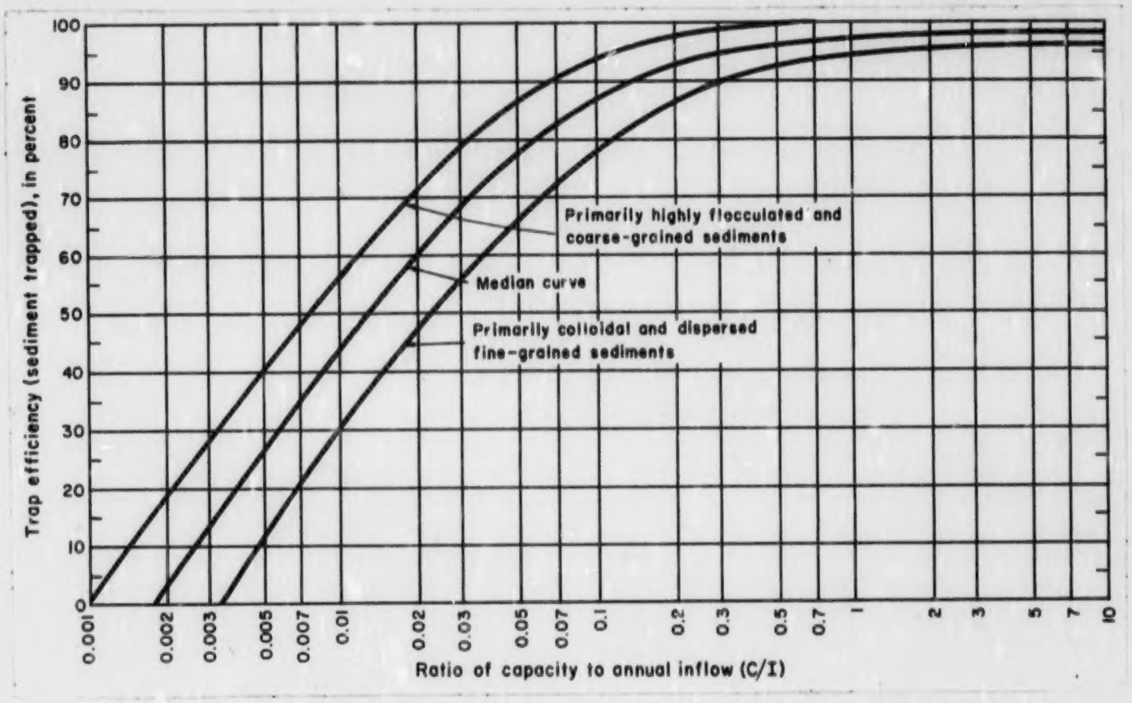


Fig. D-1. Trap efficiency as related to capacity-inflow ratio (From Ref. [D-1])

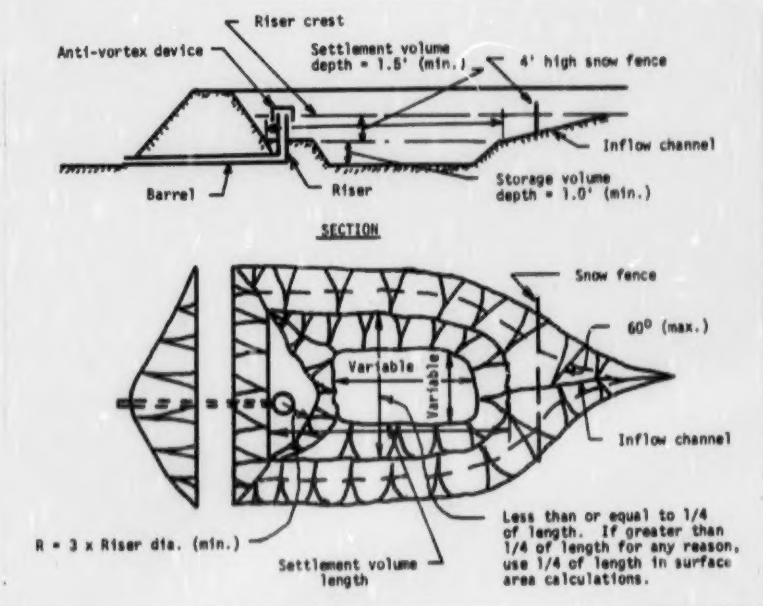
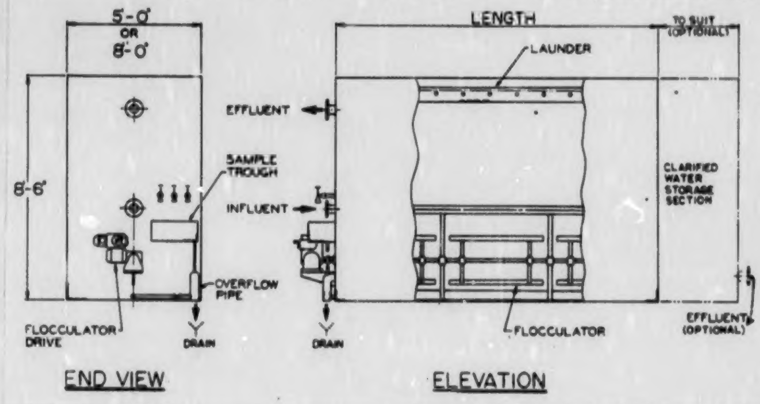
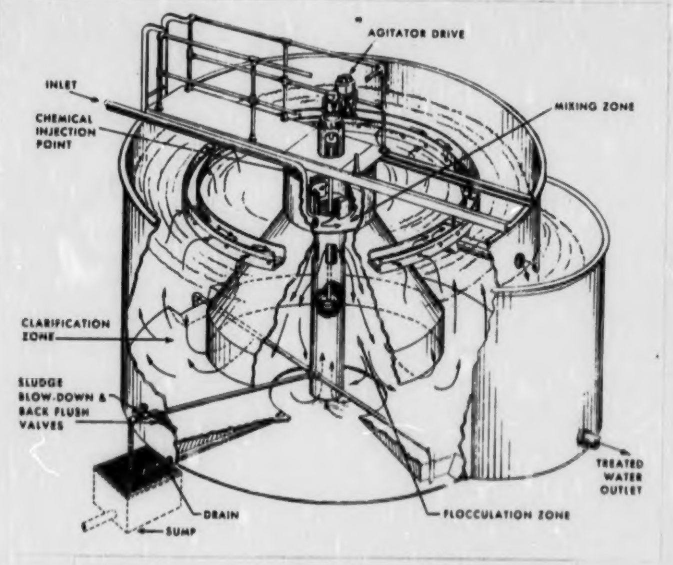

Riser crest
Anti-vortex device
Settlement volume depth = 1.5' (min.)
4' high snow fence
Inflow channel
Barrel
Riser
Storage volume depth = 1.0' (min.)
SECTION
Snow fence
60° (max.)
Variable
Variable
Inflow channel
R = 3 x Riser dia. (min.)
Settlement volume length
Less than or equal to 1/4 of length. If greater than 1/4 of length for any reason, use 1/4 of length in surface area calculations.

Fig. D-2. Suggested debris basin (From Ref. [C-6])


5'-0"
OR
8'-0"
8'-6"
SAMPLE TROUGH
FLOCCULATOR DRIVE
OVERFLOW PIPE
DRAIN
END VIEW
LENGTH
TO SUIT (OPTIONAL)
LAUNDER
EFFLUENT
INFLUENT
CLARIFIED WATER STORAGE SECTION
DRAIN
FLOCCULATOR
EFFLUENT (OPTIONAL)
ELEVATION

Size	G.P.M.	Width	Length	Influent Pipe Size	Effluent Pipe Size	Overflow Pipe Size
1	10	5'	5' 0"	1½"	2"	2"
2	20	5'	5' 0"	1½"	2"	2"
3	30	5'	7' 6"	2"	2½"	2½"
4	40	5'	10' 0"	2"	2½"	2½"
5	50	8'	8' 0"	2½"	3"	3"
6	75	8'	12' 0"	2½"	3"	3"
7	100	8'	16' 0"	3"	4"	4"
8	125	8'	20' 0"	3"	4"	4"
9	150	8'	24' 0"	3"	6"	6"

Fig. D-3. A rectangular upflow clarifier (From Ref. [D-4])


AGITATOR DRIVE
INLET
CHEMICAL INJECTION POINT
MIXING ZONE
CLARIFICATION ZONE
SLUDGE BLOW-DOWN & BACK FLUSH VALVES
TREATED WATER OUTLET
DRAIN
SUMP
FLOCCULATION ZONE

Size	G.P.M.	Tank Dia.		Tank Depth	Influent Pipe Size	Effluent Pipe Size	Ⓐ	Overflow Pipe Size	Ⓑ	Drain Pipe Size
		Standard	Special							
1	50	8' 0"	8' 6"	10' 0"	2½"	3"	9"	3"	3"	2"
2	75	10' 0"	11' 0"	10' 0"	2½"	3"	9"	3"	3"	2"
3	100	11' 0"	12' 0"	10' 0"	3"	4"	9"	4"	3"	2"
4	125	12' 0"	14' 0"	10' 3"	3"	4"	12"	4"	4"	2"
5	150	13' 0"	15' 0"	10' 6"	3"	6"	12"	6"	4"	2"
6	175	15' 0"	16' 0"	10' 0"	4"	6"	12"	6"	4"	2½"
7	200	15' 0"	17' 0"	10' 9"	4"	6"	12"	6"	4"	2½"
8	250	17' 0"	19' 0"	10' 6"	4"	6"	15"	6"	4"	3"
9	300	19' 0"	21' 0"	10' 6"	4"	8"	15"	8"	6"	3"
10	350	20' 0"	22' 0"	11' 0"	6"	8"	15"	8"	6"	3"
11	400	22' 0"	24' 0"	11' 0"	6"	8"	15"	8"	6"	3"

Fig. D-4. A cylindrical upflow clarifier (From Ref. [D-5])

SECTION E

PRINCIPLES OF LIQUID-SOLID EFFLUENT CLARIFICATION OR SEPARATION

The separation or extraction of a solid particle in suspension in water requires, in general, the presence of an all-pervading general external force or local forces, either of which serve to move the particle to a solid boundary for extraction.

Gravity, which is a mass attraction force, is the most available pervasive force. It is used for separation whenever possible. It is the dominant force in the performance of the debris or settling basin, which was discussed earlier. When space and time permit, gravity successfully motivates the entire separation process. However, as particulate size diminishes, the rate of settling decreases and removal from a large water body requires an impractical detention time. The high rate gravity tube, which is discussed later, answers this problem by subdividing the water body into small volumes, thus reducing the distance and time required for gravitational extraction of the solid.

Detention time may also be reduced by substituting powerful centrifugal forces for the weaker gravity force. In some cases this is very effective, but numerous complications arise incident to generating and using centrifugal force. Somewhat weaker centrifugal forces are provided by the hydrocyclone and teacup separator, but the mechanism to produce the force is markedly simpler than with the centrifuge. Centrifuges, hydrocyclones and the teacup separator are discussed later in this report.

Sieves or strainers, wherein the fluid passes through apertures in solids draw the solids to physical interception contact with the aperture boundaries. Mechanisms for achieving this action are discussed in the report both for the macro-sized apertures used in sieve bends or cartridge strainers and for the smaller openings of microstrainers. Virtually all of the devices called filters are also basically interception devices in much of their effective action. However, in many filters interception is very materially augmented by hydrodynamic forces and by electro-chemical forces. The latter forces, which are relatively weak in a large flow field, become very influential in the contact capture of the particle at close range in the interstices of the filter. This is particularly so for fine particles. Favorable electrochemical forces are generated by suitable addition of chemical coagulants and filter aids.

A very wide variety of filter types employ essentially fixed aperture systems for their action. In this report this includes leaf, disc, cartridge, and rotary drum types. Also included is discussion of the important but different type of aperture system which is created by the pores or interstices of a granular bed or sand filter.

Electrostatic forces may also separate particles from water by promoting the migration of the particle to an eventual attachment with a fixed boundary. The use of this force is discussed under the section on electrophoresis.

In considering the use of any of the above forces for achieving practical separation of solids, consideration must be given to the input energy requirements to achieve a workable system. These energy requirements are presently critical in the process of making the selection of a solid separating system and will become more critical as energy costs increase in the future.

SECTION F

SEPARATION BY STRAINING OR SIEVING

Separation of solids by physical interception with mechanical screens is a fairly common procedure in many types of treatment processes. This ranges from very large debris removal as with trash racks and moving bar screens on down to micro-screening with very fine mesh. Since our concern is with the smaller end of the solid size spectrum and with high flow rates, the discussion will be limited to screens which operate effectively with the smaller sizes. The present commercial offerings for this purpose appear to take three forms. These are sieve bends, tubular screens, disc and drum micro-sieves. It should be noted that virtually all filters have a basic filter medium or under drainage which is essentially a mechanical strainer, but this is overlain with various other finer media which filter with supplementary force systems. In the current case we are considering only a basic sieve or screen without supplementary components.

SIEVE BENDS AND ROTARY SCREENS

The commonest forms of sieve bends are for unwatering mixtures or for the size classification of the recovered solids. For this type of screen a variety of arrangements have been evolved for presenting the solid-water mixture to the sieve surface and for providing separate exits for the solids and water. Figure F-1 shows these arrangements for four different commercial offerings of sieve bends which essentially provide for the mixture to flow in the atmosphere and by gravity across a sloping screen. The water passes by gravity through the screen openings and the retained solids move down across the screen to eventual disposal.

For durability with solids of larger size and of an abrasive character, the actual sieve is made up of wedge-wire parallel bars securely welded to downstream back-up bars to form a rigid screen. The bar sieve is generally made of stainless steel for durability. The screen opening or slot size can be selected to match the separation requirements and the sieve is available in slot widths ranging down to 0.004 inches or a 325 Tyler mesh equivalent separation, which is equivalent to the sizes of a coarse silt. Flow rates are presumed very low for the fine sizes.

Most sieve forms are stationary in operation, but to prevent clogging, particularly with fine slots, the screen may be continuously vibrated or rapped. One form automatically rotates the screen face on a timed cycle. The rotation varies the presentation of flow from across the bars to along the bars and, thus, promotes wash-off of solids. This form, Fig. F-2, also permits varying the angle of the sieve face with the horizontal. This adjustment permits some variation of the cut-off size of the separated solids.

The capacity chart of Fig. F-2 serves to indicate the nature of the relation between the size of solid separation and the flow capacity of the unit. The smallest slot size offered (100 Tyler mesh equivalent) is equivalent to a fine sand size cut-off. Flow capacity is quite low (340 gpm) for the smallest size slot but increases rapidly as the separation size increases. It is apparent from this that mechanical sieving offers no possibility for providing complete solids separation for construction site run-off. Sieving can, however, supplant the function of the settling basin in separating out all solids larger than about 100 mesh or 0.250 millimeters which includes all sediments larger than fine sand. For flows of small magnitude a battery of sieves could replace the settling basin, but in most situations the peak flows probably dictate the use of the settling basin because it is more acceptable as to cost.

It should be noted that the sieve bend, as typified by the dimensions of Fig. F-2, requires a gravity head drop of the order of 10 feet to implement the sieve process. If this kind of head is available on-site, operations of a sieve could be quite simple. More generally the head would not be available and a pumping lift station would be added as an auxiliary. In addition to the power demands for pumping lift, power might also be required for sieve rotation or sieve tapping.

The solid waste separated by a sieve bend is dropped by gravity to accumulate below the sieve for removal. It is usually too low in water content to flow and it is normally removed by belt conveyance or trucking for disposal. The use of a sieve thus requires a continuing maintenance effort. This is in contrast to a settling basin which would usually require maintenance action only at widely spaced intervals.

A recent modification of the sieve bend (the Rotostrainer by Hydrocyclonics Corporation of Lake Bluff, Illinois) arranges the screen on the periphery of a continually rotating drum as shown in Fig. F-3. The influent is presented to the exterior of the drum near the top of its travel, a scraper blade then removes the strained solid from the exterior, and the strained liquid discharges radially outward through the drum near the bottom of its travel. The last action serves as a screen backwash. The screen is a wedge-wire of stainless steel. The screens are available in drum diameters up to 3 feet and lengths of up to 10 feet. Screen slot size ranges down to 0.01 inches (250 microns). The headloss for such a screen is about 3 feet.

THE TUBULAR STRAINER

These units consist of a large number of individual tubular metal strainers contained in a common housing which permits a pressure feed of the solids-containing mixture to the tubular screens. The screens are of a wedge-wire wound and welded stainless steel fabrication. Pressurized screening flow is radially outward through the porous wall of the tube. A power rotated backwash piping arm automatically cycles to permit backwashing of a small fraction of the tubes at all times, as shown in Fig. F-4. Screening is therefore continuous in the assembled unit.

These screens are intended for relatively coarse separation at high flow rates. A slot width of 250 microns is commonly used with a pumped differential pressure across the filter limited to 10 psi. The units are quite compact and are available in factory fabricated packages with capacities up to 85,000 gpm with 48-inch connecting pipes.

Somewhat smaller tubular strainers are available with radially inward flow and with openings down to 75 microns, Ref. [F-4]. These are of a smaller flow capacity.

THE MICROSTRAINER

The microstrainer is a mechanism for gravitationally passing a solids-containing flow through a fine mesh screen at a relatively high flow rate. With fine solids, this leads to rapid plugging or blinding of the mesh and a need for backwashing on a very short time cycle. This is all achieved with the type of arrangement shown in Fig. F-5. The strainer consists of a large, cylindrical, rotating, horizontal drum open at one end and closed at the other. The screening mesh covers the cylinder wall. The solids-containing water enters the interior of the drum axially through the open end and flow radially outward through the mesh on the cylinder wall. The drum is partially submerged so that about 75 percent of the interior screen area is presented to the flow and the drum is rotated at a speed such that the screen is exposed to the raw water for a period of as little as 20 seconds.

The solids intercepted on the screen during the passage through the raw water are rotated upward through the water surface and into the air. At the top of the drum the screen passes below pressurized water jets and the attached solids are washed downward into a stationary trough or hopper, from which they are drained and pumped for disposal. The whole operation is a continuously regenerating screening cycle.

The screen fabrics are usually of stainless steel, bronze, nylon, or polyester with a weave which provides microscopic apertures with an available size range from about 15 to 60 microns. Solids intercepted on the screen build up a mat and fines are generally removed to a considerably smaller size than the screen aperture.

The unit is generally designed to operate with a total head loss of from 12 to 24 inches. Of this total about one-third or 4 to 8 inches is the differential across the screen. Most units are available with a variable speed drive on the drum, and head loss sensors control this speed to provide an essentially constant head loss across the screen regardless of variations in solids loading in the influent. The low head loss may permit the mainflow to be processed with available gravity head without the costs of pumps and pumping. The power for drum rotation is no more than 5 HP even for the largest units.

The backwash water is screened effluent and from 1 to 5 percent of the screened flow is returned in the backwashing. The water after backwashing usually contains from 700 to 1,000 mg/l of solids. Backwashing requires about 50 psi pressure with attendant costs for pumps and pumping.

The capacity or influent flow rate depends on the rate of clogging of the screen which in turn depends on size of captured solids, solids concentration, screen porosity, drum speed, submerged screen area, and selected differential head. Normal capacities vary from about 5 to 40 gallons per minute per square foot of submerged screen. Capacity values for a given raw water can be readily determined using a small portable kit. This provides a small reservoir with a selected differential head feeding the proposed raw water mix to a tube containing a disc of the selected screen. The measured flow time before plug-up can determine a workable combination of drum speed, screen area, and screen porosity.

Commercial units are available with drums up to 10 foot diameter and 16 foot length. Capacities range from about 40 to 14,000 gpm (20 mgd) and are available with integral steel tanks or for field mounting in concrete tanks.

Flocculants are not handled well in these units but in some instances coagulants have been used effectively as filter aids. Pre-or body coating is not employed (coagulants and coatings are discussed later in Section K).

These units have been used in treating raw water and sewage plant effluents in municipal service. Some problems occur with sliming on the screens when operating with waters high in organics. Solids removal of up to 98 percent has been obtained in some service, but removal in a range from 50 to 75 percent is more likely with construction site effluent containing fines. Municipal and industrial applications commonly show effluents with less than 10 mg/l suspended solids.

Microscreens have been found to provide a fairly compact, simple, reliable, rugged, long-lived service in many separation applications. They do not require continuous attendance and initial and maintenance costs have proven acceptable in many treatment applications. Some generalized cost data [F-6] as of 1976 suggests that small units (up to 3 mgd) may involve installation costs (mechanical equipment, building and civil works) of ranges between $16,000 per mgd to $46,000 mgd for 23 micron screening and $14,000 per mgd to $18,000 per mgd including effluent tanks for larger installations. Operating costs were $5 per million gallons treated. Costs reduced substantially with coarser screen sizes.

TYPING GUIDE SHEET

THE DISC STRAINER

Disc straining is a process combining sedimentation and precoat filtration applied as an advanced solids/liquid separation technique for removing suspended solids from municipal, industrial effluents and urban stormwater runoff.

The equipment known as the Hydrocyclonics Discostrainer consists of a series of stainless steel woven wire discs mounted on a center shaft in a specially constructed chamber. The discs are approximately 50% submerged in the wastewater and rotated continuously at between 5-15 RPM. The liquid flows radially through the disc while the suspended solids are retained to form a precoat material. The unit is designed to operate with a total head loss of from 18 to 24 inches.

When the solids in the system have reached equilbrium, a waste portion is carried upwards by the revolving discs and automatically discharged from the chamber in the form of approximately 15% solids cake, as shown in Fig. F-9, leaving a precoat portion behind as filtration media. This precoat reduces the effective mesh openings to allow for filtration of suspended solids with smaller diameters than the actual mesh aperture.

The unit can be equiped with an Ultra-Violet light kill source located between the discs at the axis and radiating outward to control biological slime accumulation. This would allow for the existing bio-mass in the waste stream to be maintained for secondary activated sludge treatment. Sodium hypochlorite injection can be made within the unit to control slime growth and allow for a residual to be carried from the unit in the effluent.

A backwash system is incorporated to remove any accumulation of solids from the discs and to prevent mesh blinding. The spray back can be continuous or varied on an intermident basis dependent on the physical characteristics of the waste stream, removing accumlated solids and dropping them and the used spray water back into the filter influent chamber. Thereby the unit actually supplies its own treatment to the backwash instead of having to carry an underflow to a second treatment unit. As in most cases a pump is installed to circulate screened strainer effluent as washwater creating a closed loop system.

Wire cloths used in disc straining are available from 500 micron (35 mesh) to 45 micron (325 mesh), and the flow range for individual units is between 150-5400 GPM. Higher flow rates can be processed using multiple units.

With due consideration of the particle size disposition, type and nature of the suspended solids in the wastewater, it is considered that the disc straining technique could be usefully and economically applied in treating most municipal and industrial effluents, including combined storm sewer overflows and construction sites runoff containing silt contaminants.

With the particle agglomeration resulting from settlement and precoat filtration, the supracolloidal solids can be removed using larger mesh

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opening resulting in greater hydraulic throughputs and lower costs. Capital costs as of 1976 indicate smaller units to be approximately $20,000 per mgd with larger installations to be in the order of $15,000 per mgd. (F-10)

It does not appear that the simpler types of sieve separators will prove to be a practical answer for construction site run-off clarification for most situations. However, the microstrainer and discostrainer should be given consideration in those cases where site effluent is low in fine solids.

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[F-3] R.P. Adams Co., Adams Poro-Edge Automatic Water Strainers, Bulletin 1905, Buffalo, New York, February 1973.

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[F-6] Personel Contact with William Flipkowski, Envirosystems/Zurn Industrial, Inc. Erie, Pennsylvania, October 28, 1976.

[F-7] Envirex Co., Microscreens, Bulletin 315-171, Waukesha, Wisconisn, February 1975.

[F-8] Hydrocyclonics Corp., Rotostrainer, Bulletin RS-250-1, Lake Bluff, Illinois, 1975.

[F-9] Hydrocyclonics Corp., Discostrainer, Bulletin DS-350-0/1, Lake Bluff, Illinois, 1976.

[F-10] Personel Contact with Robert T. Manwaring, Hydrocyclonics Corp., Lake Bluff, Illinois, October 12, 1976.

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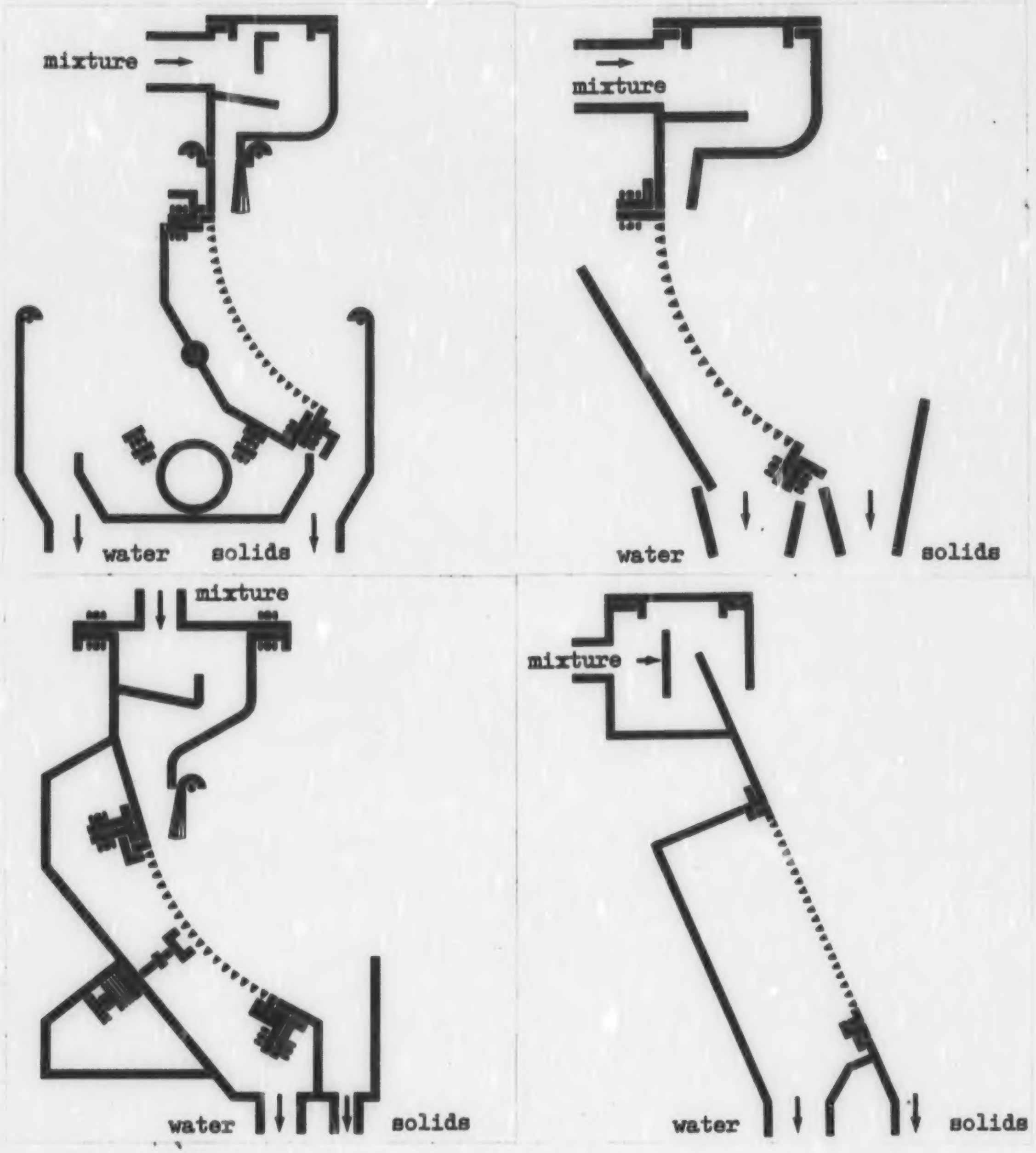
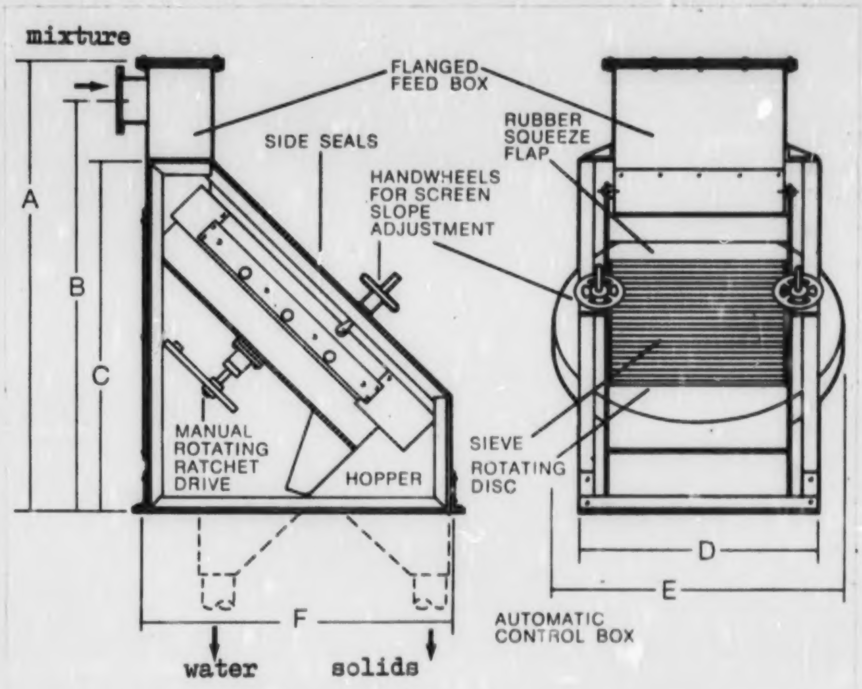

mixture
water
solids
mixture
water
solids
mixture
water
solids
mixture
water
solids

Fig. F-1. Sectional views of several commercial sieve bends (From Ref. [F-1])


mixture
FLANGED FEED BOX
SIDE SEALS
RUBBER SQUEEZE FLAP
HANDWHEELS FOR SCREEN SLOPE ADJUSTMENT
A
B
C
MANUAL ROTATING RATCHET DRIVE
HOPPER
SIEVE
ROTATING DISC
D
E
F
AUTOMATIC CONTROL BOX
water
solids

DIMENSIONS FOR GENERAL LAYOUT ONLY

SIZE	DECK SIZE	A	B	C	D	E	F
3'	3' x 2' 10"	7' 6⅜"	6' 11¾"	5' 9¾"	4' 3"	4' 10½"	4' 10"
4'	4' x 3' 10"	8' 6⅞"	7' 11 1/16"	6' 10¼"	5' 2⅜"	6' 3½"	6' 1¼"
5'	5' x 4' 10"	10' 0⅝"	9' 5"	8' 4"	6' 2½"	7' 8½"	6' 10½"
6'	6' x 5' 10"	10' 11⅛"	10' 3½"	9' 2½"	7' 2½"	9' 1½"	7' 8"

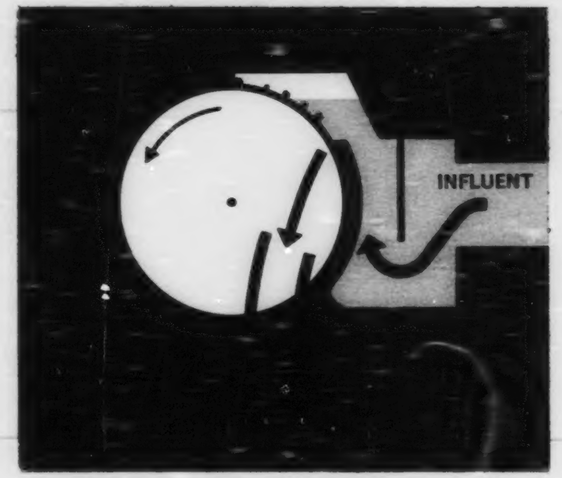
CAPACITY CHART – TYPICAL INDUSTRIAL WASTE APPLICATIONS

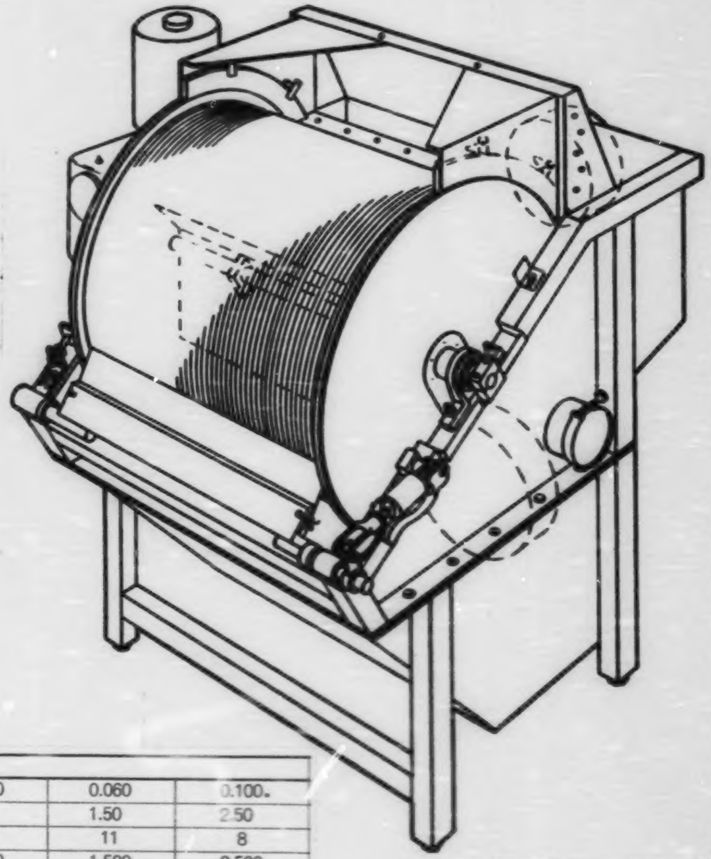
Tyler Mesh (Separation Desired)			100	48	28	16	10	8	6	5	4
Screen Opening in MM *			¼	½	1	2	3	3½	5	6	7
Screen Opening in Inches			.010	.020	.040	.080	.120	.140	.200	.240	.280
WEMCO Screen Size	Iso Bar Size **										
3'	A	U.S. Gallons Per Minute	—	50	105	165	211	250	275	290	300
	B		50	81	140	200	250	290	315	335	340
	C		65	125	200	255	300	325	350	375	390
4'	A		—	95	220	320	420	490	540	570	590
	B		100	200	340	440	500	560	600	640	690
	C		125	270	370	500	600	680	740	790	820
5'	A		—	150	370	540	680	790	870	920	950
	B		130	266	480	660	790	920	1000	1060	1090
	C		210	350	633	810	950	1040	1120	1180	1230
6'	A		—	230	550	800	1000	1140	1250	1330	1370
	B		180	320	700	970	1150	1330	1440	1530	1570
	C		340	500	900	1180	1370	1500	1600	1700	1770

* Actual Screen Opening. ** A—⅛" Iso; B—3/32" Iso; C—1/16" Iso.
Dewatering Capacity based on 60 degree Slope. Due allowance must be made for various factors contributing to actual results. All capacities were extrapolated from tests and should be used as *estimates only*.

Fig. F-2. Rotary sieve dimensions and operating characteristics (From Ref. [F-2])

Rotostrainer®





Flow capacities. The flow capacity chart shown below is established on the basis of raw sanitary sewage which has a suspended solids level of approximately 200 mg/liter

	CYLINDER OPENINGS													
INCHES	0.010		0.020		0.030		0.040		0.050		0.060		0.100	
MILLIMETERS	0.25		0.50		0.75		1.00		1.25		1.50		2.50	
MESH EQUIV.	60		32		22		16		13		11		8	
MICRONS	250		500		750		1,000		1,250		1,500		2,500	
MODEL	**U.S. GPM**	**MGD**	**U.S. GPM**	**MGD**	**U.S. GPM**	**MGD**	**U.S. GPM**	**MGD**	**U.S. GPM**	**MGD**	**U.S. GPM**	**MGD**	**U.S. GPM**	**MGD**
RSA-2512	125	.18	225	.3	300	.43	375	.55	425	.6	475	.7	550	.8
RSA-2524	250	.36	450	.6	600	.86	750	1.1	850	1.2	950	1.4	1100	1.6
RSA-2548	500	.7	900	1.3	1200	1.7	1500	2.2	1700	2.4	1900	2.7	1900	2.7
RSA-2572	800	1.2	1330	1.9	1850	2.7	2250	3.2	2580	3.7	2900	4.2	2900	4.2
RSA-36120	1450	2.1	2550	3.7	3500	5.0	4450	6.4	5200	7.5	6000	8.6	7800	11.2

Fig. F-3. Rotating sieve drum and operating characteristics (From Ref. [F-8])

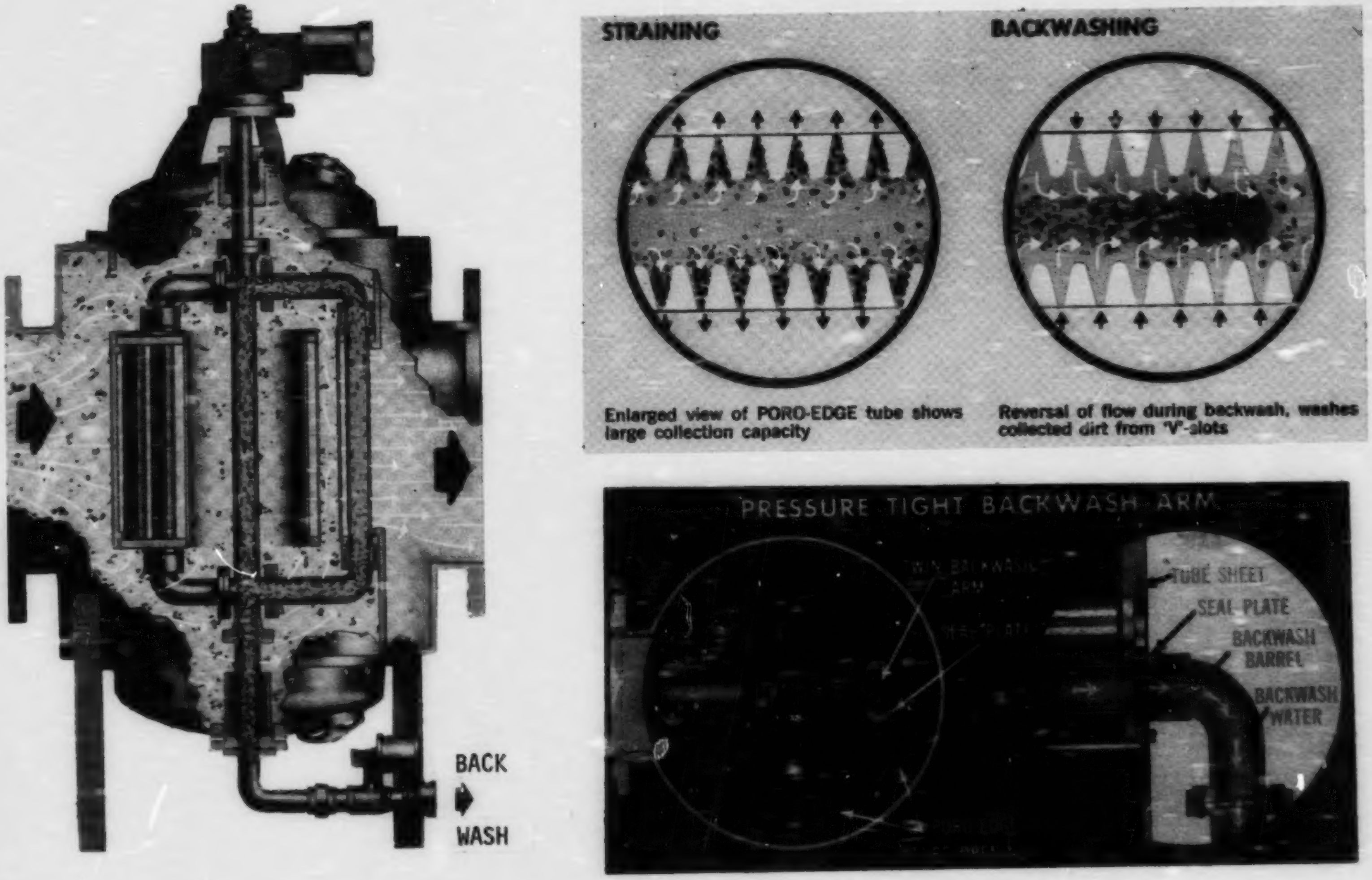

BACK
WASH
STRAINING
BACKWASHING
Enlarged view of PORO-EDGE tube shows large collection capacity
Reversal of flow during backwash, washes collected dirt from 'V'-slots
PRESSURE TIGHT BACKWASH ARM
TUBE SHEET
SEAL PLATE
BACKWASH BARREL
BACKWASH WATER

Fig. F-3. High rate tubular strainer with automatic power rotated backwash arm (From Ref. [F-3])

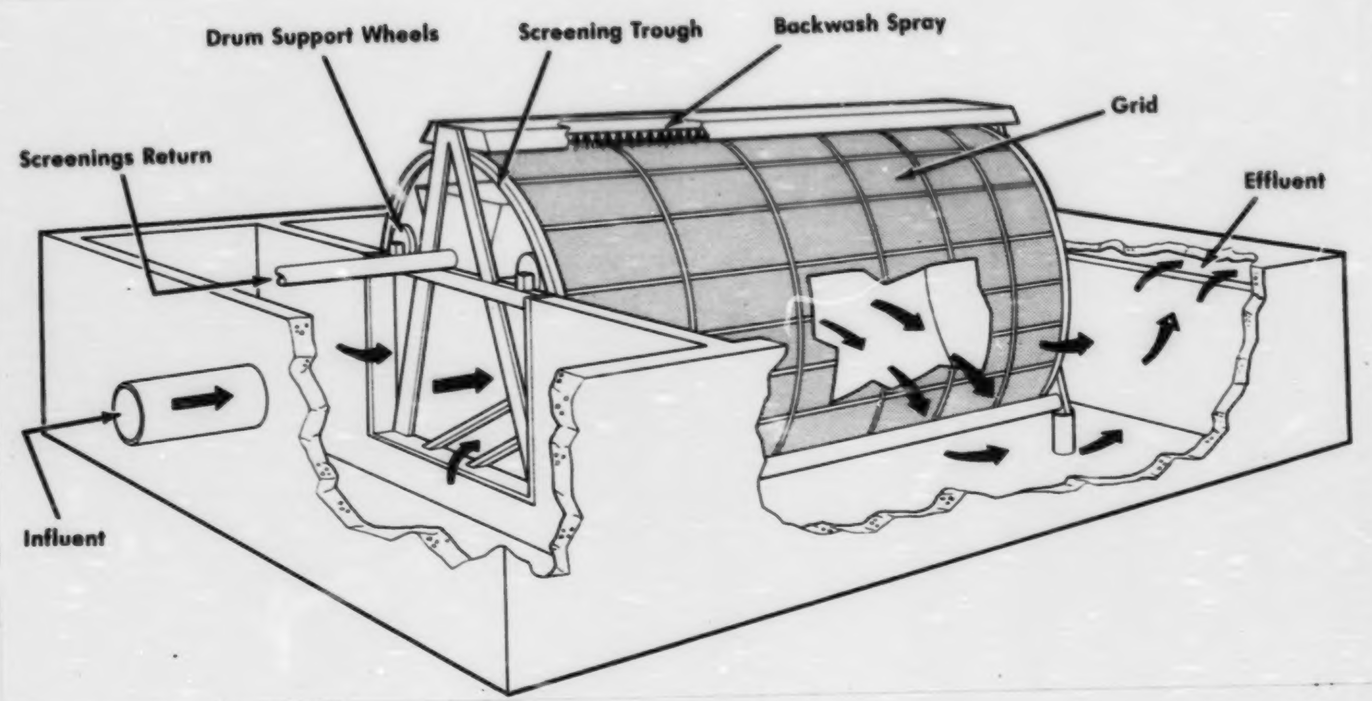

Drum Support Wheels
Screening Trough
Backwash Spray
Grid
Screenings Return
Effluent
Influent

Fig. F-4. A drum type microscreen unit (From Ref. [F-7])

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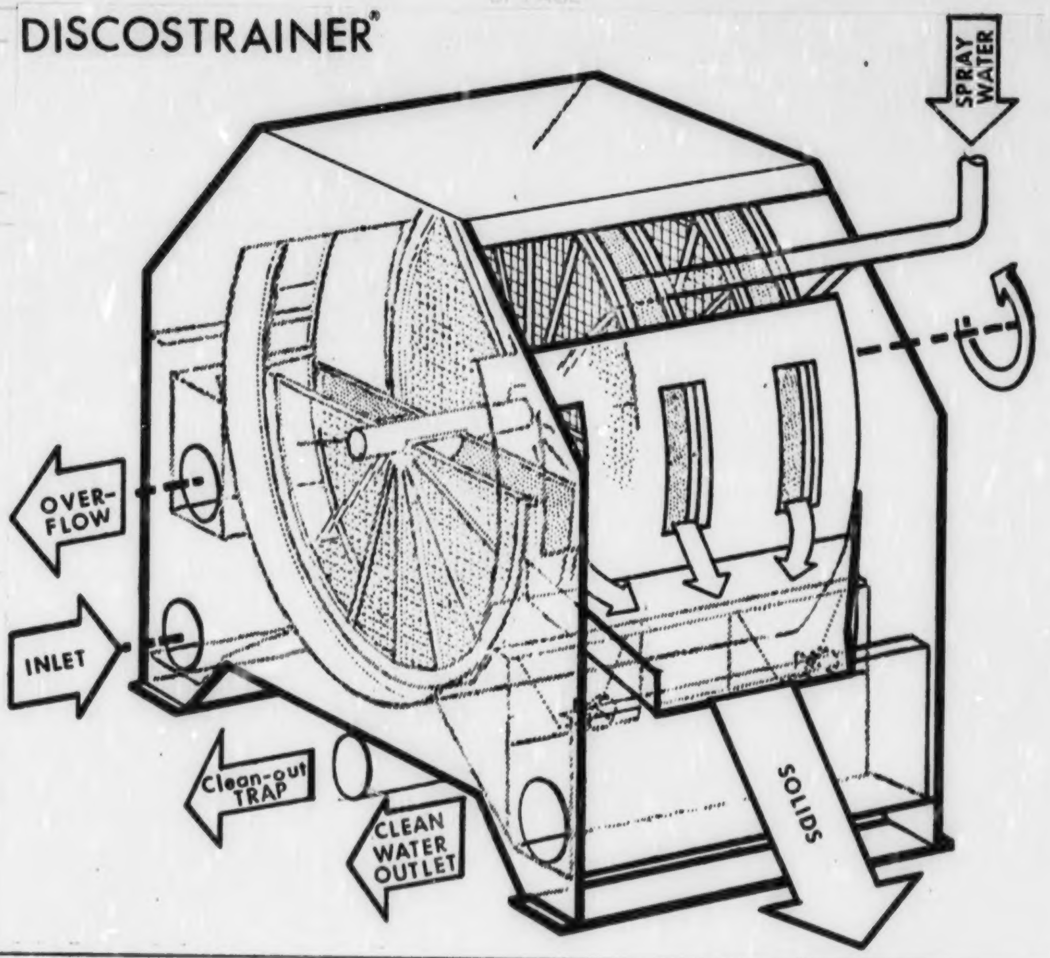

MODEL SIZES AND CAPACITIES

Model	Capacity GPM 2	Motor HP 1	No. of Discs	Disc Dia.	Filter Area Sq. Ft.	Approx. Dimensions L.	W.	H.
DS-3902	150	3/4	2	39"	16.1	2.6'	4.9'	4.6'
DS-3904	300	3/4	4	39"	32.3	3.6'	5.6'	5.0'
DS-3906	470	3/4	6	39"	48.4	4.6'	5.6'	5.0'
DS-4706	675	2	6	47"	67.8	5.8'	6.9'	6.1'
DS-4708	900	2	8	47"	90.4	6.9'	6.9'	6.1'
DS-4712	1,360	3	12	47"	135.6	9.0'	6.9'	6.1'
DS-5908	1,480	3	8	59"	145.3	7.3'	8.5'	7.9'
DS-5912	2,200	4	12	59"	219.6	9.6'	8.5'	7.9'
DS-5916	2,900	4	16	59"	290.6	11.9'	8.5'	7.9'
DS-7112	3,200	4	12	71"	322.9	11.5'	9.6'	8.4'
DS-7116	4,300	5.5	16	71"	430.6	14.3'	9.6'	8.4'
DS-7120	5,400	7.5	20	71"	538.2	17.0'	9.6'	8.4'

1. Drive motor HP only, does not include spray pump motor.
2. Ratings are for .008" (200 microns) openings in raw sanitary sewage with suspended solids of 300 ppm or less. Flow rates will vary with application and suspended solids levels.

Fig. F-6. Rotating disc screen and operating characteristics (From Ref. [F-9])

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3/8"

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SECTION G

HIGH RATE GRAVITY SEPARATORS

Early investigators of solid removal by gravity settling established that efficiency of removal improved with increasing surface area of the settling basin and diminishing depth. In simple settling tanks it is difficult to practically achieve high settling efficiency by increasing the areal extent of the tank to decrease the depth. However, it was long ago established that passing the flow through stacked spaced plates could, in effect, decrease the settling depth, thus achieving a large settling area but within a compact total area. Plate type separators have been developed for this process. In general, they have proven somewhat difficult to clear of the settled solids. More recently (Refs. [G-1, G-2]), a practical solution has been found in the tube type settler in which the flow space of the settling basin is broken down into an assembly of 2 inch by 2 inch tubes of about 24 inch length. Such tube assemblies provide a small settling depth and consequent short detention time and have a compact space requirement when compared to conventional rectangular settling basins.

The most promising commercial units available in this country appear to be those of Neptune Microfloc, Inc. of Corvallis, Oregon and Ecodyne-Graver of Union, New Jersey. These units have cells of 2 inches by 2 inches inclined at 60° to the horizontal, and assembled of plastic sheet into a module. Figure G-1 shows a module which is 10 feet long by 30 inches wide by 21 inches deep. A unit which is functionally quite comparable to Fig. G-1 but differs in module fabrication is made by Pielkenroad Separator Company of Houston, Texas. With such modules disposed near the exit end of a channel or basin, and with their tops a small distance below the normal free surface in the basin, flow is arranged to enter from the bottom, pass upward through the tubes, and exit at the top. During passage upward, the heavier solids settle to the bottom of the sloped tube. Because of the steep slope of the tube axis, the settled solids move down the tube invert in a counter-current flow and drop out of the tube bottom. With the bottom of the tube module placed well above the basin floor, the material deposited on the basin floor may be either continually or periodically collected and removed.

The system is operated at flow rates which maintain a low Reynolds number in the tube and a laminar flow. The units are designed for, and most operating experience is with, sewage or water treatment plants where the water is flocculated to remove fines. Most of the solids in this case are non-settlable without flocculation. Effective through-flow or overflow rates, in terms of gallons per minute of flow per square foot of horizontal plan, are in the range of 2 to 5. The lower value is associated with near freezing temperatures where the higher water viscosity hinders the settling rate. The higher flow rate is associated with higher operating temperatures. The 2 to 5 gpm/sq. ft. rate compares to a value of about 1 gpm/sq. ft. for conventional rectangular settling basins. A rate of 4 gpm/sq. ft. is equivalent to approximately 6,000 gallons per day per square foot and gives a detention time of about 4 minutes.

Observations suggest that much of the effectiveness of solids removal using flocculation relates to the fact that a suspended floc zone develops below the bottom of the tubes and all approaching flow moves through this zone for good floc interaction. Solids removal in the range of 75 to 95 percent has been achieved and evidence indicates that the tube system is far less sensitive to flow conditions than a conventional settling basin.

Measurements with properly flocculated inflow have shown that flow rates of 2 to 4 gpm/sq. ft. will produce effluent turbidity values ranging from 1 to 10 Jackson Turbidity Units (see Section B for JTU), and about 20 milligrams per liter of solids with sizes less than 10 microns. Effectiveness of solids removal generally improves with increasing solids concentration in the influent.

Almost all of the available field data relates to flocculated organic solids of a non-settlable type. Performance with largely mineral solids is relatively unknown but estimated to be very good, although capture of colloidally suspended clay fines would probably require flocculation for effective removal.

The relative simplicity of this system's physical structure, lack of need for start-up or shut-down preparation, inherent corrosion resistance, and freeze protection recommend its consideration for installation in conjunction with a minimal debris basin. Basically, it provides about the same potential as a simple gravity debris basin but in about 1/3 the surface area. Where sufficient area is available for inexpensive construction of a debris basin, the high rate gravity separator is probably not attractive, but in some instances it may prove an effective solution. Its addition to a settling basin imposes no additional energy requirements.

LIST OF REFERENCES

[G-1] Reprinted from "Tube Clarification Process, Operating Experiences," Journal of Sanitary Engineering Division, October 1969, by Culp, G.L., K. Hsiung, and W.R. Conley, with permission of the American Society of Civil Engineers.

[G-2] Yao, K.M., "Design of High Rate Settlers," Journal of Environmental Engineering Division, ASCE, October 1973.

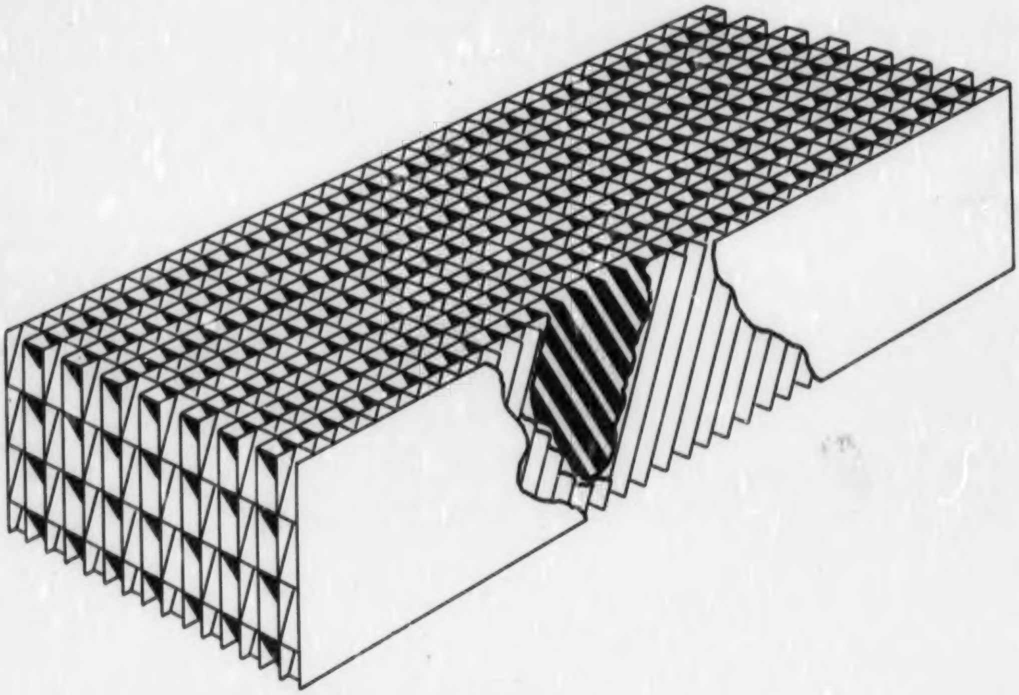


Fig. G-1. Installation module for an inclined-tube high-rate settler (From Ref. [G-1])

SECTION H

SEPARATION USING A HYDROCYCLONE, SWIRL CONCENTRATOR OR TEACUP SEPARATOR

INTRODUCTION

In the discussion of Section E dealing with the basic forces used to separate solids from water, mention was made of gravitational forces and centrifugal forces. Gravitational systems are limited to a mass attractive force which is given by force = mass x g where g is the local gravitational acceleration. On the other hand rotating centrifugal force generators involve motion of a mass particle on a curved path with a radius, r, and a tangential velocity V_T. Under these conditions the acceleration in a radial direction is given by $a_r = V_T^2/r$ and the centrifugal force is given by force = mass x a_r. Unlike the gravitational force which is limited by the available natural value of g, the centrifugal force can be greatly enhanced by designing the rotor with large values of V_T or small values of r. Under this enhanced force system even small solid particles can achieve fairly high settling velocities in fluid suspensions. With suitably shaped rotors, migration or settling of the particle can be achieved in a relatively short residence time and in a compact space. Some types of centrifuge devices achieve accelerations which are of the order of 10,000 times the gravitational value g. It is obvious that separation devices employing centrifugal force can have unique potentials.

In the material which follows three available types of rotary flow devices will be described. These include the hydrocyclone, the swirl concentrator and the teacup separator.

The hydrocyclone is a simple fixed configuration which largely employs a high static pressure in the inflow water to induce a strong hydrodynamic vortex within which centrifugal forces develop to separate entrained solids from the water. The centrifuging action is accomplished with stationary walls containing the fluid suspension rotating about a vertical axis. The centrifugal force field (100 to 1,000 times that of gravity) in the hydrocyclone produces a moderately high rate of settling in a horizontal plane and little or no vertical gravitational settling is involved. The relative simplicity of the hydrocyclone generally favors easy construction, low initial capital investment and modest operating costs except for a significant energy demand.

The swirl concentrator employs very low static pressures to produce a gentle inwardly spiralling rotary flow and has a simplicity of arrangement of stationary parts which superficially appears analagous to the hydrocyclone in its flow mechanics. Actually the velocities that are usually used are so low and the radius of flow path so large that centrifugal accelerations are a small fraction of the vertical gravitational acceleration. Solid separation is thus primarily achieved by simple gravitational fall velocities and centrifugal forces are of little consequence. Separation is confined to the larger solids but energy demands are kept small.

The teacup separator is a more recent development which has attempted to improve the separation characteristics of the swirl generator. It does this by combining some of the geometric features of the swirl generator with those of the hydrocyclone and by increasing the velocity and diminishing the radii employed in the swirl concentrator. In consequence centrifugal forces play a dominant role in the separation, and operating energy costs are of significance.

THE HYDROCYCLONE

The most common physical form of the hydrocyclone is usually as shown in Fig. H-1 and consists of a basic large cylinder with a lower tapered cone, both usually disposed along a common vertical axis. The inflow feed pipe is arranged tangential to the main cylinder and positioned at or above the middle of the cylinder. The commonest inflow pipe entrance shape is a simple circle, but in some forms the approaching circular pipe gradually changes to a high, narrow, rectangular exit opening. The fluid containing solids enters tangential to the cylinder wall at a moderately high velocity due to the static pressure driving the feed flow. Because of the much lower pressure maintained at the underflow end of the cone, the differential pressure drop produces a strong rotary vortex action spiralling downward in the cylinder and cone as shown in Fig. H-2. This vortex generates centrifugal forces on the liquid and its heavier contained solids and causes the solids to migrate to the outer wall and spiral down to the cone end. Most of the solids exit through the end of the cone with a small amount of water to form the underflow. The bulk of the water exits at the top overflow with a small amount of unseparated fine solids. This discharge results from an upward spiralling vortex which develops in the core of the cyclone as shown in Fig. H-2. The outer vortex spiralling downward and the inner vortex spiralling upward produce an intermediate zone in which vertical velocity is zero as shown in Fig. H-3.

As a consequence of the high speed vortex action, a central core of air usually forms. This is to be expected where the overflow and underflow discharges are directly to the atmosphere. However, even with piped discharges, which provide no free surface to vent the core, free gas may be released from solution and will migrate to the core. In very strong vortices the pressure may drop below vapor pressure with formation of a core which is partially vapor.

The seemingly simple geometry of a hydrocyclone is deceptive. Actually, the internal flow mechanics are quite complex and available theoretical relationships have generally been oversimplified to the point where they do not provide acceptable prediction of performance unless tempered by experimentally determined coefficients. In the treatment which follows, graphical material based on physical experiments with a conventional form of cyclone is used to give insight into the performance characteristics of cyclones. Hopefully, this information will be sufficient to permit preliminary consideration of units for use in construction cleanup studies, but it is suggested that commercial suppliers be consulted relative to their specific offerings before final selections. Fortunately, a substantial number of suppliers exist in a competitive market. Some suppliers are listed in Fig. H-4. The list is the result of a limited search and is not considered all inclusive.

The division or split in flow at the base of the cone which leads to the separate under-and overflow is largely controlled by the size of aperture which is fitted at the base of the cone. This may be an opening of fixed size or a variable area orifice. The latter is frequently provided by using an elastic discharge sleeve which can be pinched to produce area changes. This controlled split of the water flow also produces a split in the solids load carried in the water with a near maximum practical concentration of the larger size particles going to the underflow and a smaller concentration and size of particle going to the overflow. For a consistent flow of solids at the inflow of a given hydrocyclone, the approximate maximum size of particle which will remain in the overflow and which will be largely absent in the underflow is primarily determined by the cylinder diameter, the drop in pressure between the inflow and underflow, and the aperture. Optimal design is still essentially a matter of experimental adjustment of conditions.

The nominal size of the cyclone is based on the diameter of the top cylinder, D_c, as shown in Fig. H-1. In practice this may vary from about 1/2 inch to 36 inches. The proportions of other geometric parts of the cyclone relative to D_c vary considerably in practice and, in general, performance has been found relatively insensitive to changes in proportions and is intended to separate out the larger sizes of solids (up to 1-1/2 inches) with a considerable water and solids handling capacity. If smaller sizes of solids are to be separated, stronger centrifugal action is needed and is achieved with small diameter cyclones operated at higher pressure drops (up to several hundred psi) and in multiple stages. Because of limited capacity in individual units, the small cyclone must be arranged in parallel in multiples to achieve large capacity. This necessitates manifolded connections to common inlet, underflow, and overflow. Despite the relatively high operating costs for pumping power when using small cyclones for fines separation, they have proven practical in a wide variety of industrial separation problems because of the value of the liquid or solid recovered. However, in the cleanup of construction site runoff neither the liquid nor solid has commercial worth and the cost of fines removal will face some practical limit. This then leads to consideration of larger cyclones with lower pressure drops for removal of coarser solids.

Cyclones may be designed for use as washers, classifiers, and deslimers, but those designed for major removal of solids are generally known as thickeners and the efficiency is measured with respect to the recovery of all of the solids in the inflow with an underflow delivery as free of water as possible. It is usually not economical to use a cyclone for separating large particles because gravity and screening methods can be used at less cost. In consequence, cyclones have found greatest usefulness for a particle size range from about 5 to 200 microns. This is a range which includes all normal silts and fine sands but does not include clays. They may, however, be used to remove solids as large as 1-1/2 inches. The use of flocculants to capture smaller sizes in a cyclone is of no practical value because the high internal shear in the cyclone mechanism destroys the floc.

A cyclone can in principle be designed to fit a wide variety of problems, but a given design is relatively inflexible in operating over any wide range of conditions. In consequence, cyclones are frequently considered as a complement to, rather than a replacement of, other devices such as centrifuges or filters which are more flexible in operation.

CYCLONE SIZE AND WATER FLOW CAPACITY

The water flow capacity of a cyclone of common proportions varies as a function of cyclone size. This variation is graphically depicted by Tarr [H-3] in Fig. H-5. For this figure it is assumed that the pressure drop is 10 psi.

The influence of a change in pressure drop from the basic value of 10 psi is discussed elsewhere under "Head Loss or Pressure Drop" and is graphically shown in Fig. H-6.

As solids are added to the inflow, water capacity increases. Figure H-7 shows the nature of this change relative to the basic values of Fig. H-5.

SEPARATION SIZE

The mineral solids which are presumed to constitute the bulk of the solids in runoff from a construction site usually will have a specific gravity of about 2.7. For the common form of cyclone (see Fig. H-1) the preferred concentration of solids in the inflow should be about 20 percent by weight or about 10 percent by volume. For these conditions, a given size of cyclone will produce a "separation" (considered to be the coarsest particle size which has a total weight of 1 to 5 percent in the overflow) which is approximated by the graph of Tarr [H-3], Fig. H-8. In this, the shaded area is the more normal range to be expected. The lines to the left and right of the shaded area indicate the range of sizes which may be separated by varying certain dimensions and operating conditions on a given size of cyclone.

It should be noted that the larger size solids shown in Fig. H-8 are not limiting sizes that can be removed. Large low pressure cyclones have been used for preconditioning flows having solids as large as 1-1/2 inches.

If the inflow concentration percent of solids by volume varies from the basic 10 percent value assumed in Fig. H-8, the separation particle size derived from Fig. H-8 can be corrected for a different operating concentration in accord with the curve of Fig. H-9.

If the pressure drop differs from the basic 10 psi assumed in Fig. H-8, the separation particle size derived from Fig. H-8 can be corrected for a different pressure condition in accord with the curve of Fig. H-10. This correction constitutes a good approximation for pressures between 3 and 50 psi and is poorer for values outside this range.

Typical separation data for a 14-inch conventional form of cyclone is shown in Fig. H-11.

HEAD LOSS OR PRESSURE DROP

The head loss or drop in pressure between a flow point immediately before feed entry and immediately after overflow exit provides the driving force or energy which produces the separation action. The overflow is used for reference because it is usually the larger of the two discharges and it is also the stream most involved in subsequent flow considerations. Some investigations relate only to the feed pressure but in view of the fact that back pressures sometimes exist in the discharge, it is more meaningful to refer to the pressure drop.

Conventional cyclones are generally designed to operate with a pressure drop ranging from 5 to 50 psi. This range is relatively independent of cyclone size, but for some small size cyclones the pressures may be carried to several hundred psi. Greater separational effects may be achieved by increasing the pressure drop, but this soon becomes uneconomical and single cyclones rarely operate over 70 psi.

Graphical summaries of the relation between the cyclone diameter, inflow capacity, and pressure drop are given in Figs. H-5 and H-6 from Tarr [H-3]. These are useful for preliminary study purposes and relate to cyclones having common dimensional proportions. Figure H-5 gives the flow capacity characteristics of different sizes of cyclones operating with a pressure drop of 10 psi while Fig. H-6 shows the correction to capacity that must be applied for operating with pressures other than a basic 10 psi.

The cyclone pressure drop is also influential in the separation or cut-off size to be expected in operation. This is discussed elsewhere under "Separator Size" and is graphically summarized for common cyclones in Figs. H-6 and H-8.

CONCENTRATION VALUES AND VOLUME SPLIT

A common design preference for a hydrocyclone is an input feed concentration of around 10 percent solids by volume or 20 percent solids by weight for a solid specific gravity of about 2.7. Concentrations which are significantly more or less than this value operate with less overall effectiveness. With this level of inflow concentration, the underflow concentration can be quite high but is limited by the fact that the opening must permit enough water to pass so that the underflow will flow readily. The smaller the volume of underflow water the smaller the amount of fine material appearing in the underflow. The minimum underflow volume is considered to be about 1 percent of the inflow volume and more normally it is about 15 percent.

The effectiveness of the solids removal for a given operating condition is inherently related to the size distribution of the solids in the inflow as well as to their concentration.

Industrial cyclones may need to be operated at steady and near optimum load conditions to achieve relatively high efficiency. However, the use of cyclones to clarify construction runoff involves highly variable loading and unmanned control. While automated control is possible, the cost for this limits its adoption. In consequence, cyclones for construction runoff may be expected to operate with some pre-selected apex opening which may not always operate under conditions of optimum effectiveness during the runoff period.

In simple systems with the underflow directly to atmosphere, it may be necessary to add some back pressure at the underflow in order to prevent negative pressures in the overflow. The latter condition may promote undue carry-over of fines into the overflow.

Some insight into typical concentration, split, and size distribution values may be obtained from Fig. H-11 which shows data using a 14 inch conventional cyclone for thickening or separating fine sand from a flow.

RESIDENCE TIME AND SPACE REQUIREMENTS

The space requirement for facilities to clarify construction runoff water is probably not a critical factor in the selection of a type of facility to be employed out-of-doors, but comparative values may be useful to planning. Similarly, the residence time of the water in the facility is also a factor of use in comparative considerations.

For a cyclone of conventional proportions and the common range of pressure drop employed (5 to 50 psi) Bradley, Ref. [H-2], found that the average residence time in seconds could be approximately expressed $T = 0.91\ D_c$ for a pressure drop of 50 psi. In this D_c is the diameter of the cyclone in inches.

Bradley states that the floor space requirements for a vertical cyclone range from about 200 to 700 gal./min./sq. ft. If the cyclone is installed horizontally, the value falls to about 100 gal./min./sq. ft. In comparison, gravitational types of separators may require a space varying from several hundred to several thousand times as much and centrifuges may require ten times as much.

ABRASIVE WEAR CONSIDERATIONS

The nature of flow in a cyclone produces a moderately high rate of shear between the solid particles and the internal boundaries of the cyclone. With sustained operations this shear leads to significant abrasive action and material loss from the boundaries with relatively short life. Because of the simple construction of the cyclone, fabrication in common low carbon steel is relatively inexpensive and replacement of the entire unit is sometimes an acceptable economic solution to abrasive wear. Metallic alloys with greater abrasive resistance are available and cyclones may be fabricated with these to provide greater life. The cost of these fabrications are considerably higher than with ordinary steel.

Another alternate for extending the life of a cyclone is the provision of renewable rubber liners for all active surfaces. This complicates the construction and increases the expense but has proven practical despite the fact that ultimately such liners must also be replaced after severe service.

For smaller cyclones the cyclone may be built entirely of hard abrasion-resisting ceramics or elastomerics such as polyurethane.

If a cyclone were to be considered for clean-up of construction site runoff, the relatively brief operating period suggests that a relatively inexpensive cyclone constructed of common steel is a satisfactory compromise.

In centrifuges the walls rotate with the fluid and its solids, and wall erosion is much less severe than in a cyclone.

THE PUMPING SYSTEM

In most applications of a cyclone the inflow water does not inherently possess the static pressure level necessary to operate the cyclone. In consequence, the capital costs must usually include the necessary pressurizing pump and pumping circuit and operating costs must include the pump power.

Based on the energy delivered to the water, the power requirements for pumping are given by Bradley Ref. [H-2] as:

$$HP = \Delta pQ/1725$$

where Δp is pressure drop across cyclone in psi and Q is inflow discharge in U.S. gallons per minute.

For cyclones operating in the conventional range of 5 to 50 psi, the equation gives values of $HP = 0.0029$ per gpm at 5 psi and $HP = 0.029$ per gpm at 50 psi.

Centrifuges for comparable duty may require much larger horsepowers which may range from about 0.2 to 0.7 per gpm.

The pumps employed for pressurizing are generally of the centrifugal type but modified to reduce internal wear due to the abrasive character of the pumped solids. Pumps of this character are known as slurry pumps and are built to process flows in which the solid size is not larger than 1/4 inch. This presumes preliminary settling or screening of the pumped flow.

A general workable arrangement for the cyclone and its supply pump and discharges is shown in Fig. H-12. The sump should provide detention storage for not less than one minute of flow and should provide not less than six feet of head on the pump suction. The two-compartment sump shown in the figure aids in maintaining a constant suction head to permit a constant cyclone feed and pressure drop.

Cyclones may be obtained in a wide variety of sizes but for many installations the needs can be conveniently answered by assembling a number of intermediate sized units. Such typical assemblies using 12-inch basic cyclones packaged for field use are shown in Fig. H-3 together with capacity, size, weight, pump, and cost data (1975). The pumping units called for in Fig. H-13 are further defined in Fig. H-14. These units are skid mounted for field use.

COST DATA

Cost data are of course dependent on a wide range of variables that may be involved in the assembly of a particular cyclone system. However, some insight into costs are given in the tabular data (1975) of Fig. H-13. This data is roughly confirmed by a rule of thumb value Ref. [H-6] of $120 per inch of diameter (1975).

THE SWIRL CONCENTRATOR

The swirl concentrator is intended as an auxiliary treatment device for the removal of larger solids from storm runoff. The concentrator is unable to remove the smaller fines and in most cases must be followed by other removal facilities. The concentrator serves to improve the efficiency and reduce the storage of these other removal facilities.

The device superficially appears similar to a hydrocyclone in general arrangement but actually does not employ centrifugal action for solids separation. It is instead essentially a compact grit chamber or detention basin depending on gravitational fall velocity for solids separation.

The configuration recommended for solids separation in field use is shown in Fig. H-15 and is the outgrowth of a long series of studies conducted on behalf of the U.S. Environmental Protection Agency by the American Public Works Association. Design criteria and step-by-step design procedures for the unit are contained in Ref. [H-7].

The unit shown in Fig. H-15 is intended to be inexpensive, portable, and recoverable for use at construction sites. It is accordingly assembled around a standard, light-weight, metal, livestock watering tank. The basic cylindrical tank is in this case 12 foot in diameter, flat-bottomed and 3 feet deep. An inner tank of 8 foot diameter and 9 inch depth is placed concentric with the outer tank with the top of the small tank 2 feet above the floor of the larger tank. The inner tank is supported on a central, vertical, 2 foot diameter, exit pipe.

The outer tank is fed by a 2 foot wide pipe or channel with the entering flow baffled to be tangential to the walls of the two tanks. The induced circular flow gradually slows as its clearer upper portion is progressively decanted into the shallower inner tank. The gradually slowing lower flow retains the bulk of the deposited and suspended solids. The clearer, decanted water or overflow discharges through the 2 foot diameter central pipe while the solid-carrying underflow discharges continuously through a 6 inch diameter foul water outlet. The proportion of the flow that is drawn off through the foul water outlet is regulated by a valve.

Tests on a 1/4 scale model were conducted with the draw-off varying from 5 to 14 percent of the inflow. Solids removal for the 12 foot full size unit were predicted from the model results and are as shown in Figs. H-16 and H-17 for solids of specific gravity 2.65. These figures predict that all solids larger than 350 microns will be removed if the total discharge is no larger than 3.4 cfs. If the discharge is increased to 8.5 cfs, 80 percent of these larger particles will still be removed with a flow draw-off of 14 percent. Sixty percent will be removed with a draw-off of 5 percent. Because of the very limited detention time in the concentrator, solids smaller than 350 microns will be only partially removed or recovered and the percent recovered will vary as a function of the particle size and total discharge as shown in the figures. Reference [H-7] also provides data for predicting the removal of solids of specific gravity other than 2.65.

It is apparent from the above that a swirl concentrator design for best efficiency at a total flow of 3.4 cfs has excellent accomodation for substantial storm overloads. Recovery efficiency will diminish under such overload conditions but substantial removals will occur. For a given site condition the 12 foot swirl concentrators would be installed in parallel in numbers which would handle the peak runoff with individual units operating with Q = 3.4 cfs. Installation of the units require little more than the provision of elementary trash screening and a site energy head or head loss of about 2 feet.

It is intended that the clarified overflow from the concentrator be routed either to a receiving water or to additional treatment as dictated by the water quality standards of the site. The solids-carrying underflow would be routed to a solids lagoon for further settling before routing to the receiving water or additional treatment. The size of the solids lagoon would be dependent on the peak run-off rate and the percent draw-off elected for the swirl concentrator operations.

It is conceivable, that with the addition of coagulants, recovery of fines would be materially enhanced.

Full scale tests are underway at a number of field installations but operating and cost data are not currently available.

THE TEACUP SEPARATOR

The teacup separator is a recent proprietary development of Eutek Systems of Sacramento, California [H-8] designed to improve on the swirl concentrator by separating finer solids than the swirl generator through use of centrifugal forces for separation. The physical makeup of the teacup is as shown in Fig. H-18 and bears a strong resemblance to the hydrocyclone of Fig. H-1. The principal difference is the addition of a horizontal floor placed slightly above the conical bottom.

Solids, which migrate toward the vertical wall of the cylinder through horizontal centrifugal settling, spiral downward through vertical gravitational settling. The coarser solids settle to the horizontal floor and spiral inward on this floor and drop through a central hole in the floor. These solids may be continually withdrawn at a low rate through the underflow valve at the bottom of the cone or may be withdrawn periodically after a thickening action has taken place through quiescent holding in the cone. The teacup separator is so named because the sediment motion along the horizontal floor is similar to that of the tea residues in a cup of tea which has been rotated and then stopped.

The teacup separator is of larger physical size than a conventional commercial hydrocyclone of comparable flow rate and presumably operates with lower centrifugal forces and more significant gravitational effects through a longer residence time. The diminished centrifugal action would presumably lead to lower pumping energy requirements than for the hydrocyclone but probably would still require pumping plant and pumping energy at most sites. The teacup separator gives promise of supplying a useful solids separator for construction site runoff but pertinent performance data is not currently available. While the separation cut-off size for the teacup can probably be made significantly smaller than that of the swirl concentrator, the teacup would very probably pass some of the finer silts and all of the clays. For some sites this would necessitate subsequent treatment.

LIST OF REFERENCES

[H-1] Reprinted from "The Theory and Applications of the Hydrocyclone," Solid-Liquid Separation, 1966, by Kelsall, D.F., with permission of Her Majesty's Stationery Office, London.

[H-2] Reprinted from The Hydrocyclone, 1965, by Bradley, D., with permission of Pergamon Press, Oxford.

[H-3] Tarr, D.T., Practical Application of Liquid Cyclones in Mineral Dressing Problems, Krebs Engineers, Menlo Park, California, 1965.

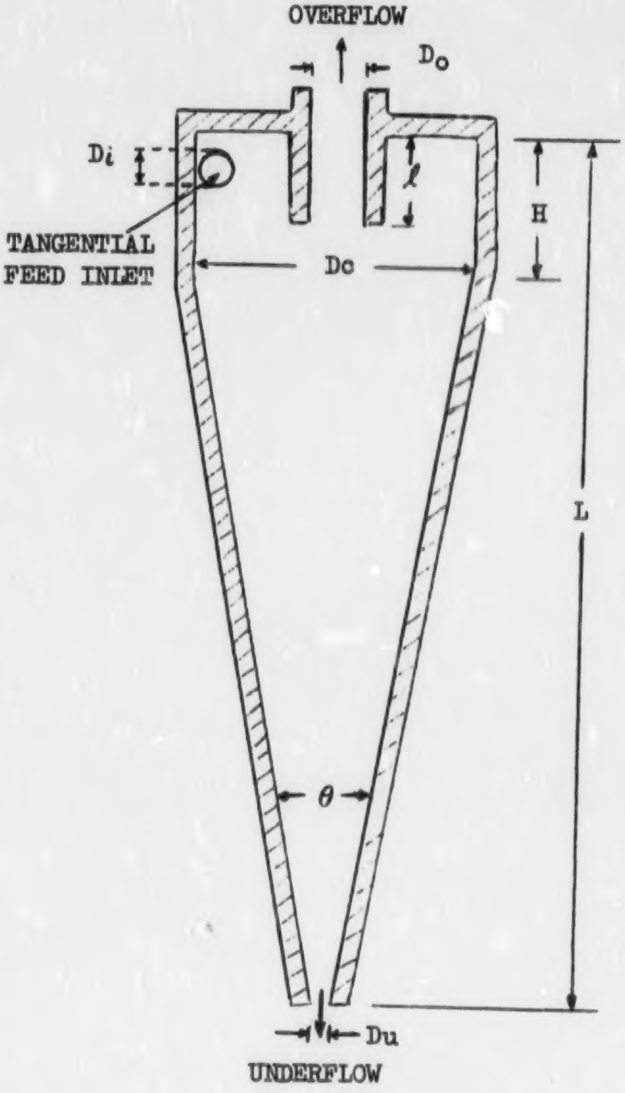
[H-4] Heyl & Patterson, Inc., The Heyl and Patterson Cyclone, Catalog 1157, 1975.

[H-5] Demco, Inc., Demco Centrifugal Separators, Catalog C-75, 1975.

[H-6] Private communication from R.A. Arterburn of Krebs Engineers dated 5-27-75.

[H-7] Sullivan, R.H., Cohn, M.M., Ure, J.E., Parkinson, F.E., and Zielinski, P.E., The Swirl Concentrator for Erosion Runoff Treatment, Contract Number 68-03-0272, U.S. Environmental Protection Agency, 1976.

[H-8] Private communication from J.Y.C. Huang, Eutek Systems dated 7-13-76.


OVERFLOW
Do
Di
ℓ
H
TANGENTIAL FEED INLET
Dc
L
θ
Du
UNDERFLOW

Common Values

$D_i = D_c/7$

$D_o = D_c/5$

$D_u = D_c/15$

$\theta = 10^\circ - 20^\circ$

$\ell = .4\ D_c$

$L = 5\ D_c$

$H = D_c/2$ to D_c

Fig. H-1. The common hydrocyclone (After Kelsall [H-4])

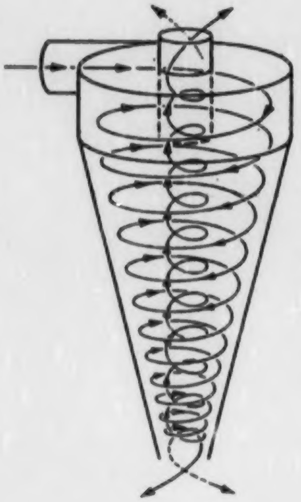


Fig. H-2. Schematic representation of the spiral flow (From Bradley [H-2])

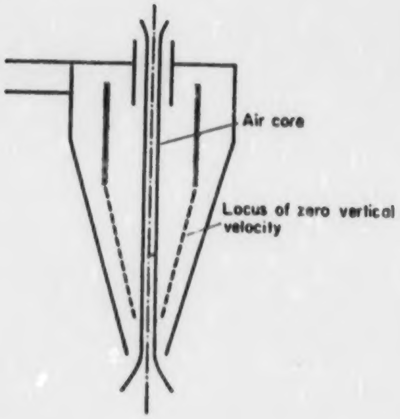

Air core
Locus of zero vertical velocity

Fig. H-3. Schematic representation of the locus of zero vertical velocity and the air core (From Bradley [H-2])

Centr-Spray Corp., 3900 Schoolcraft Road, Livonia, Michigan

Demco, Inc., 829 S.E. 29th Street, Oklahoma City, Oklahoma

Heyl & Patterson, Inc., Seven Parkway Center, Pittsburgh, Pennsylvania

Krebs Engineers, 1205 Chrysler Drive, Menlo Park, California

Laval Separator Corp., P.O. Box 6119, Fresno, California

Polyclon, Inc., 15 Sixth Road, Waburn, Massachusetts

Rex Chainbelt, Inc., Waukesha, Wisconsin

WEMCO, 721 North B Street, Sacramento, California

Fig. H-4. A list of American makers of hydrocyclones

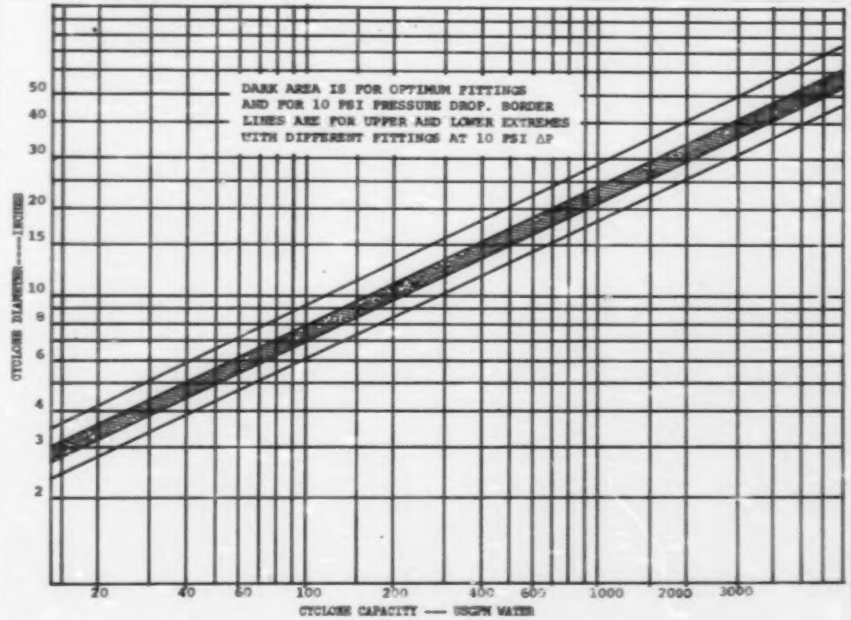


Fig. H-5. Optimum cyclone capacity vs. cyclone diameter (From Ref. [H-3])

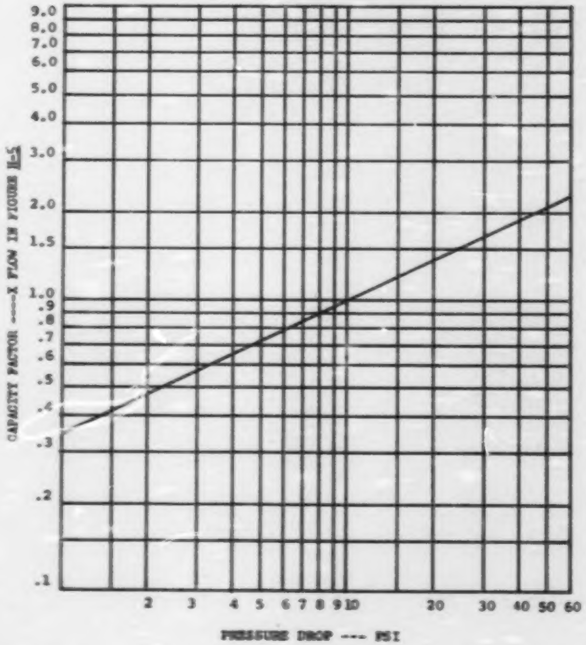


Fig. H-6. Cyclone capacity vs. pressure drop (From Ref. [H-3])

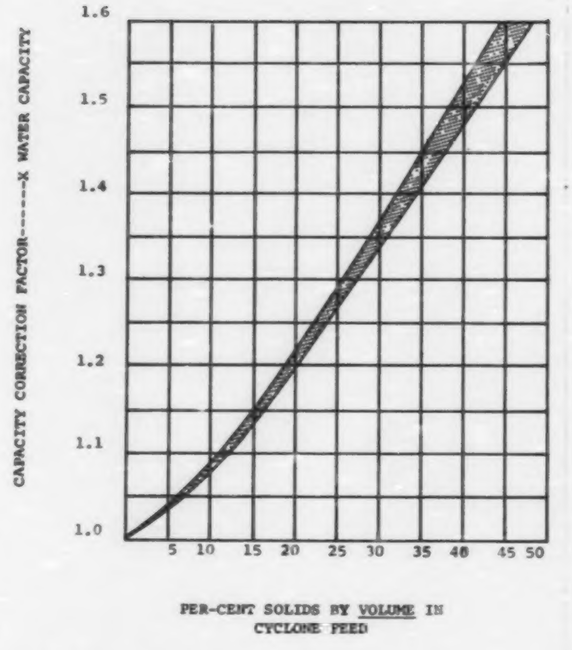


Fig. H-7. Effect of feed solids on cyclone capacity (From Ref. [H-3])

(increasing the percent solids in the cyclone feed will increase capacity at constant pressure drop)

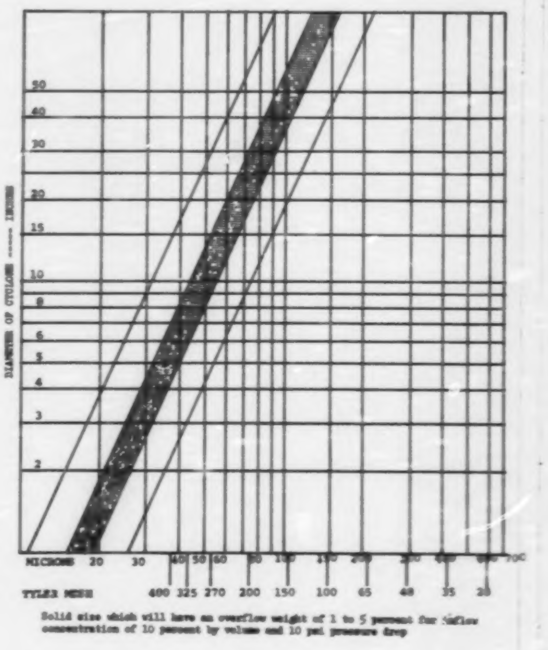


Fig. H-8. Cyclone diameter vs. separation (From Ref. [H-3])

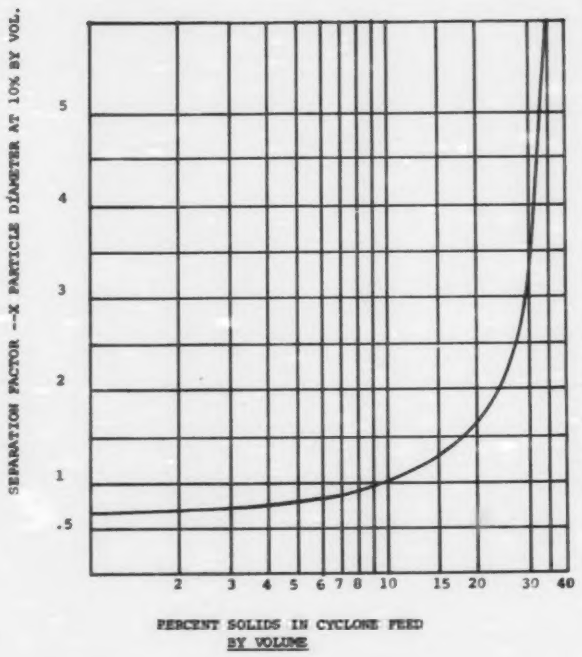


Fig. H-9. Effect of feed percent solids on separation (From Ref. [H-3])

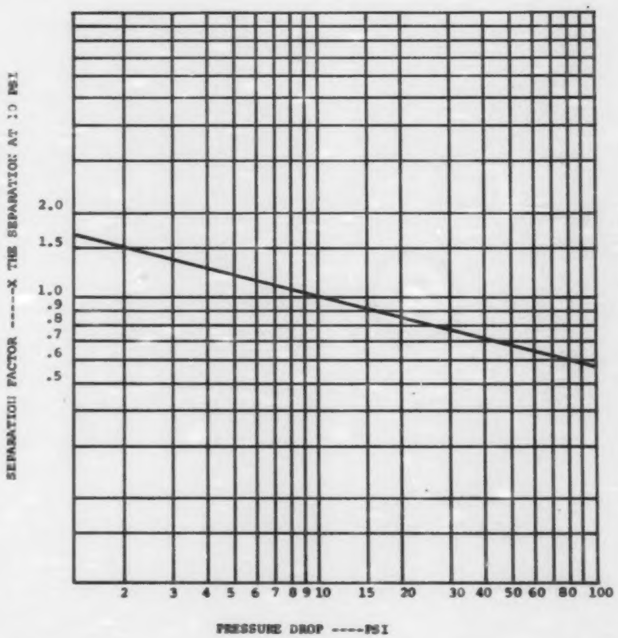


Fig. H-10. Effect of pressure drop on separation (From Ref. [H-3])

Application: Thickening and classifying fine SAND.
Feed Pressure: 20 PSIG *Flow*: 560 GPM per cyclone *Solids Specific Gravity*: 2.6

Size Microns and Tyler Mesh	Feed	Underflow	Overflow
0- 44 Microns	6.4%	0.7%	31.5%
325-200 Mesh	7.4%	2.7%	28.3%
200- 65 Mesh	52.2%	55.0%	40.2%
65- 28 Mesh	28.0%	34.3%	....
28- 16 Mesh	4.0%	4.9%	....
> 16 Mesh	2.0%	2.4%	....
	100.0%	100.0%	100.0%
	Feed	Underflow	Overflow
Concentration by Weight	11.2%	70.2%	2.1%
Recovery		81.6%	

Remarks: This Cyclone removes fine clays from the sand feed and delivers an "ongrade" underflow product of 70.2% concentration. This rubber-lined cyclone with ceramic or rubber underflow orifices, and rubber-lined overflow orifice, provides a high-capacity, long lasting recovery unit built especially for the sand industry.

Fig. H-11. Typical separation test data for a 14-inch cyclone (From Ref. [H-4])

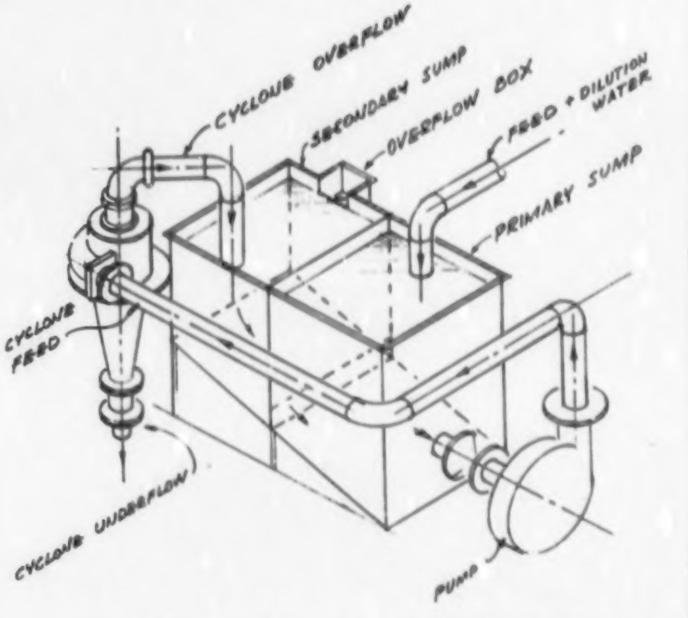
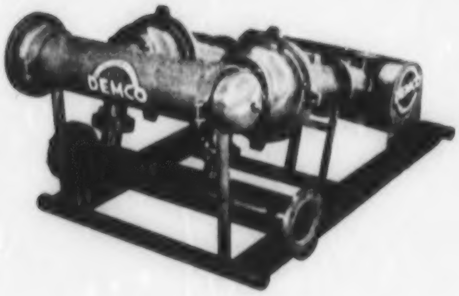
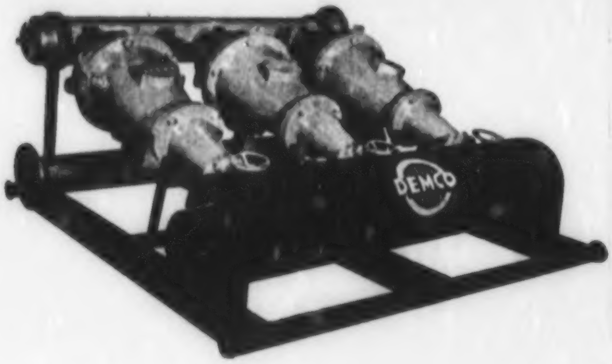

CYCLONE OVERFLOW
SECONDARY SUMP
OVERFLOW BOX
FEED + DILUTION WATER
PRIMARY SUMP
CYCLONE FEED
CYCLONE UNDERFLOW
PUMP

Fig. H-12. Hydrocyclone arrangement with control sump and slurry pump (From Ref. [H-3])



MODEL 122

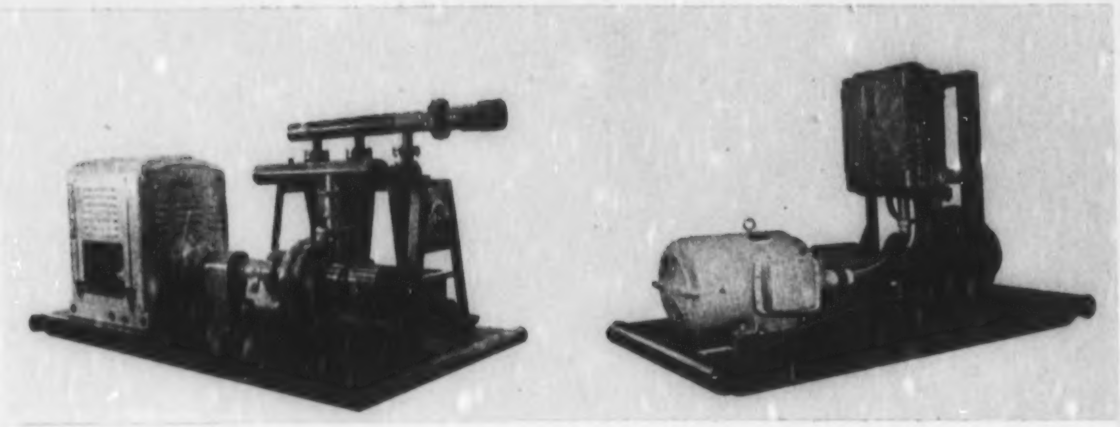


MODEL 123

12" DESANDER ASSEMBLIES WITH ORIFICE CONTROL

Model	Description	Open System	Approx. Wt. Lbs.	Approx. Dim. L-W-H	Capacity GPM	Power & Pump*
12	One 12" Cone with 3" ASA 150 Flange Inlet and 6" Victaulic Groove Overflow, Orifice Control	#1195-221 1166.00	315	2' x 2' x 4'	350-450	A, D, H or L
121	One 12" Cone on a Skid—Inclined, with Underflow Trough	#1471-021 1529.00	675	6' x 3' x 3'	350-450	A, D, H or L
	One 12" Cone on a Stand—Vertical, with Underflow Trough	#2915-021 1529.00	750	3' x 3' x 6'	350-450	A, D, H or L
122	Two 12" Cones on a Skid—Inclined, with Underflow Trough	#1206-021 3184.50	1450	6' x 4' x 3'	700-900	B, F, G, J or M
	Two 12" Cones on a Stand—Vertical, with Underflow Trough	#2916-021 3184.50	1650	4' x 3' x 6'	700-900	B, F, G, J or M
123	Three 12" Cones on a Skid—Inclined, with Underflow Trough	#4651-021 4834.50	2225	6' x 6' x 3'	1050-1350	G, J, K, or M
	Three 12" Cones on a Stand-Vertical, with Underflow Trough	# 8550-021 4834.50	2300	6' x 4' x 7'	1050-1350	G, J, K, or M
124	Four 12" Cones on a Skid —Inclined, with Underflow Trough	#6755-021 6484.50	3050	6' x 8' x 4'	1400-1800	K or P
	Four 12" Cones on a Stand-Vertical, with Underflow Trough	# 8614-021 6484.50	3100	8' x 4' x 7'	1400-1800	K or P

Fig. H-13. Assembly of 12-inch hydrocyclones for field use (From Ref. [H-5])

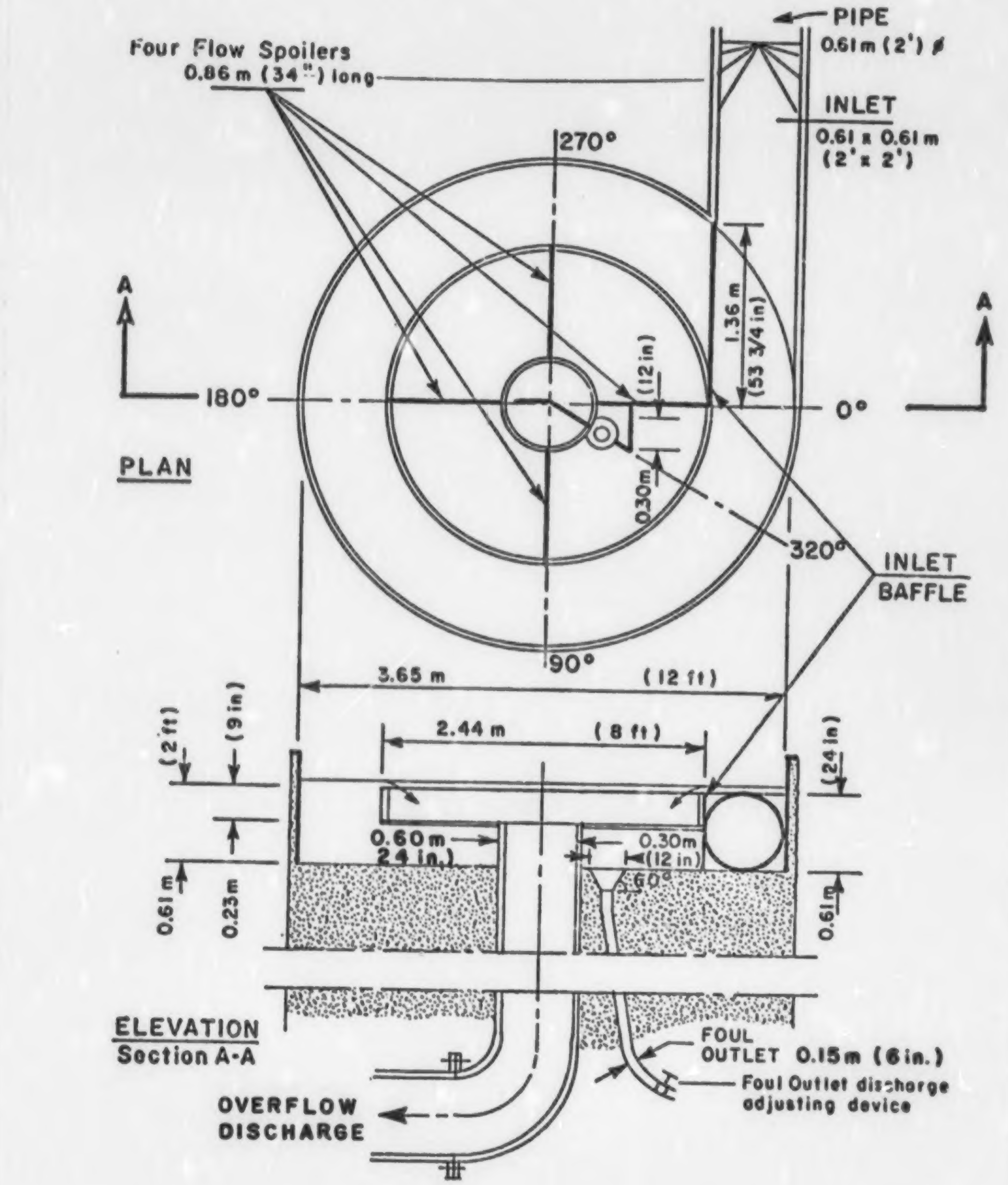


DIESEL **ELECTRIC**

POWER AND PUMP ASSEMBLIES
PRICE ON APPLICATION

Key	Description	Continuous B.H.P.*	Optional Accessories
	Electric—Belt or Direct Drive		
C	20 HP Motor with 5 x 6 Pump, Skid		240 Volt Starter
D	30 HP Motor with 5 x 6 Pump, Skid		
E	40 HP Motor with 5 x 6 Pump, Skid		240 Volt Starter
F	50 HP Motor with 5 x 6 Pump, Skid		
G	60 HP Motor with 6 x 8 Pump, Skid		240 Volt Starter
P	75 HP Motor with 6 x 8 Pump, Skid		240 Volt Starter
	Diesel—Direct Coupled		
H	GMC 2-71, Model 2031 Engine with 5 x 6 Pump, Skid	40-44	Air Starter Safety Switches
I	GMC 3-71, Model 3031C Engine with 5 x 6 Pump, Skid	60-67	
K	GMC 4-71, Model 4031C Engine with 6 x 8 Pump, Skid	80-95	
L	Perkins Four 236 with 5 x 6 Pump, Skid	48-57	Air Starter Safety Switches
M	Perkins Four 300 with 5 x 6 Pump, Skid	54-63	

Fig. H-14. Field mounted pumping units for use with hydrocyclones of Fig. H-13 (From Ref. [H-5])



Four Flow Spoilers
0.86 m (34") long
PIPE
0.61 m (2') ø
INLET
0.61 x 0.61 m
(2' x 2')
270°
180°
0°
90°
320°
A
A
1.36 m
(53 3/4 in)
(12 in)
0.30 m
PLAN
INLET
BAFFLE
3.65 m
(12 ft)
2.44 m
(8 ft)
(2 ft)
(9 in)
(24 in)
0.60 m
24 in.)
0.30 m
(12 in)
60°
0.61 m
0.23 m
0.61 m
ELEVATION
Section A-A
FOUL
OUTLET 0.15 m (6 in.)
Foul Outlet discharge
adjusting device
OVERFLOW
DISCHARGE

Fig. H-15. A 12 foot diameter swirl concentrator (From Ref. [H-7])

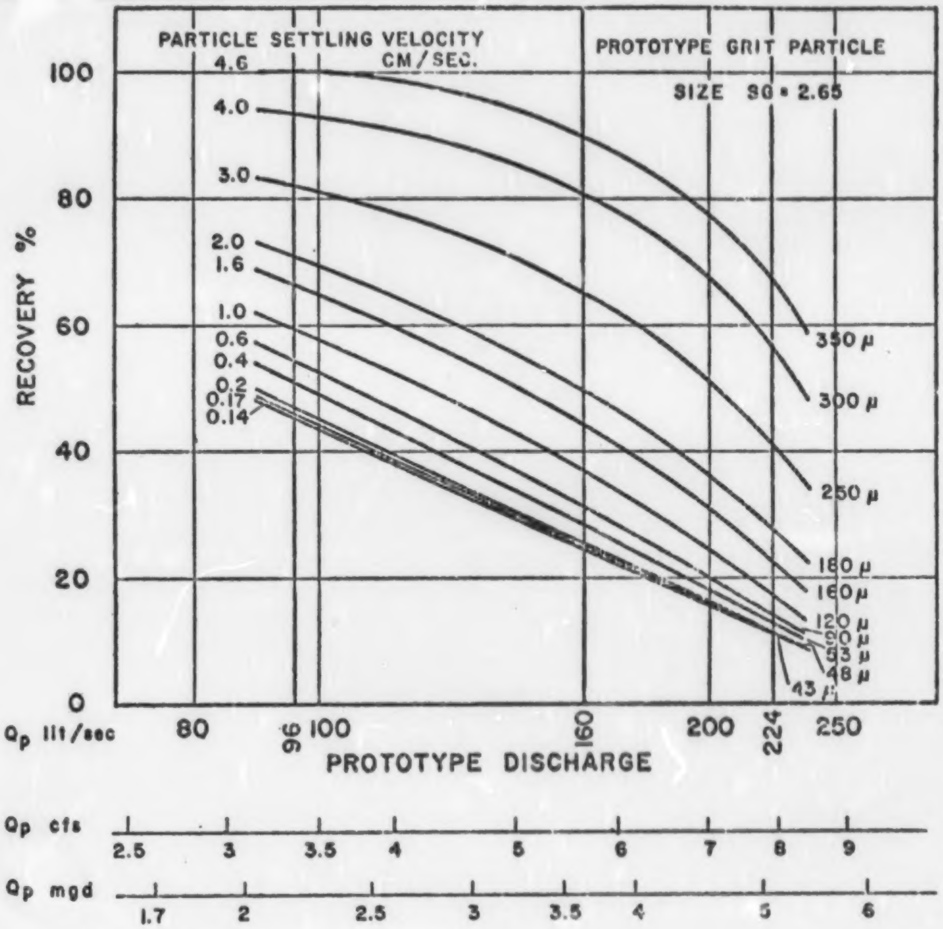


Fig. H-16. Predicted solids recovery for a 12 foot diameter swirl concentrator operating with a 5 percent draw-off (From Ref. [H-7])

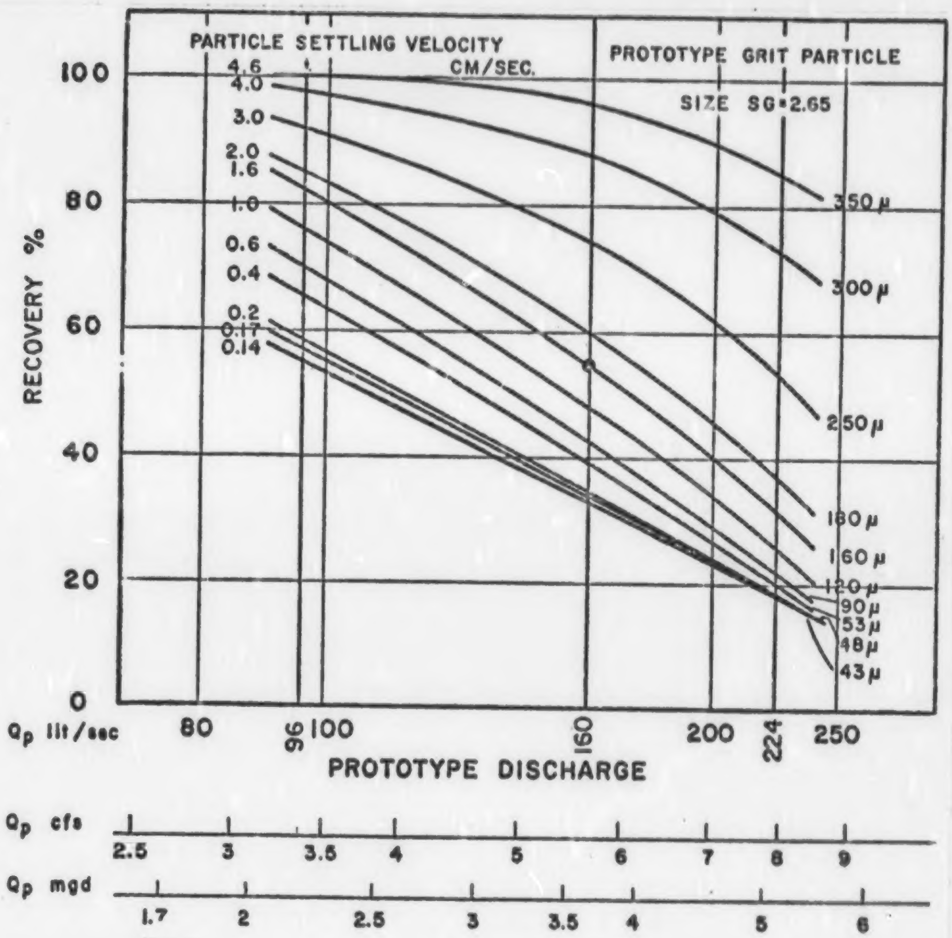


Fig. H-17. Predicted solids recovery rates for a 12 foot diameter swirl concentrator operating with 14 percent draw-off (From Ref. [H-7])

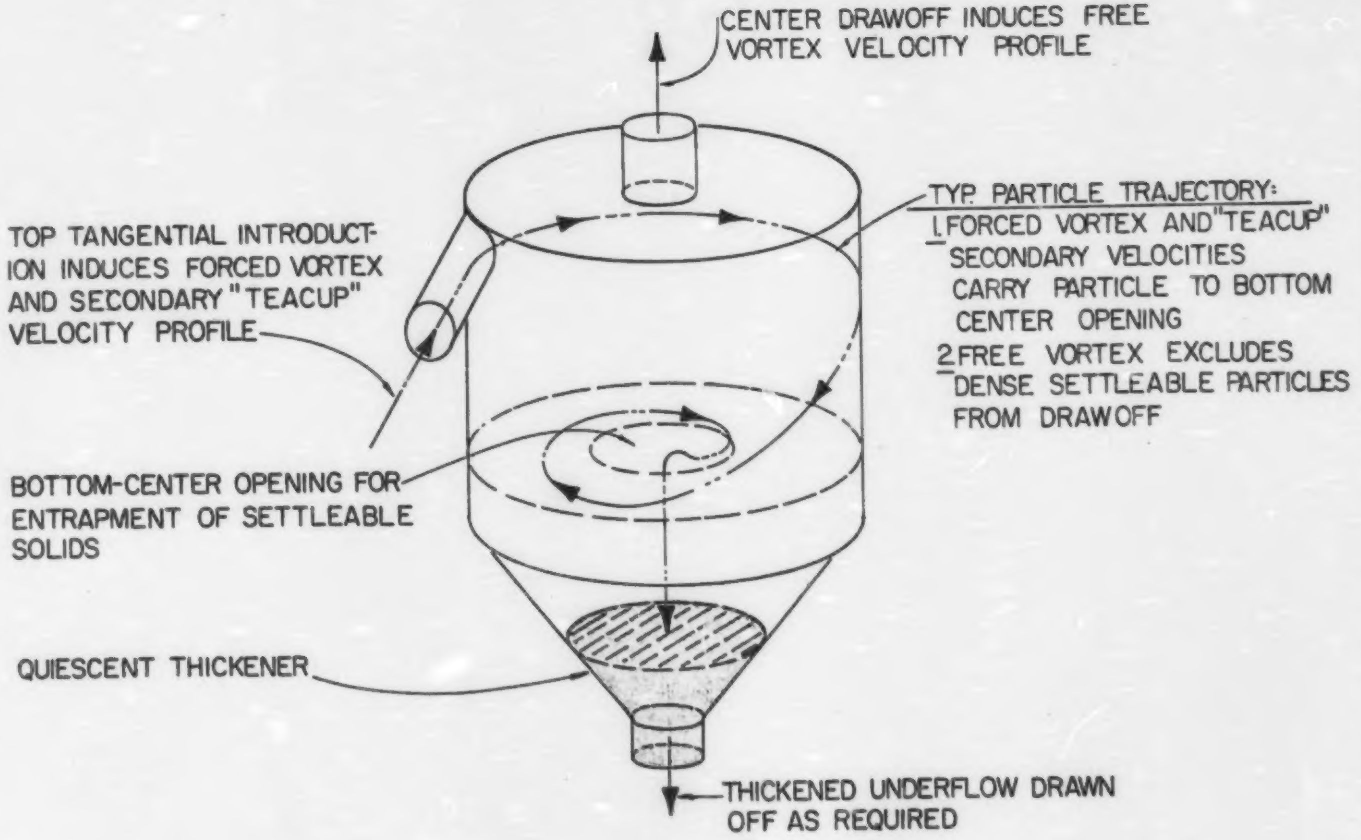

CENTER DRAWOFF INDUCES FREE VORTEX VELOCITY PROFILE
TOP TANGENTIAL INTRODUCTION INDUCES FORCED VORTEX AND SECONDARY "TEACUP" VELOCITY PROFILE
TYP. PARTICLE TRAJECTORY:
1. FORCED VORTEX AND "TEACUP" SECONDARY VELOCITIES CARRY PARTICLE TO BOTTOM CENTER OPENING
2. FREE VORTEX EXCLUDES DENSE SETTLEABLE PARTICLES FROM DRAWOFF
BOTTOM-CENTER OPENING FOR ENTRAPMENT OF SETTLEABLE SOLIDS
QUIESCENT THICKENER
THICKENED UNDERFLOW DRAWN OFF AS REQUIRED

Fig. H-18. The teacup solids separator

SECTION I

SEPARATION BY CENTRIFUGES

Centrifuges are similar in principle to hydrocyclones in that they separate the solid from the liquid by what is in essence an accelerated gravitational action. They physically differ from the hydrocyclone in that the liquid-solid mix is contained within a solid boundary and rotates with the boundary with little shearing interaction. In the cyclone the boundary is stationary and the liquid-solid mix rotates within the boundary thus producing internal fluid shear. The inherent mechanical problems associated with the structure of a continuous feed centrifuge makes it a much more complex and expensive device than the cyclone so that its use is not recommended if a cyclone will suffice.

The prime advantage of the centrifuge is that it can quite practically subject the liquid-solid mix to a considerably higher centrifugal force than the hydrocyclone can. For the centrifuge, effective g values in production types may range from 1500 to 8000. In consequence, the separation size of the centrifuge can readily be reduced to 0.1 micron and for laboratory and ultracentrifuges to 0.01 and 0.001 microns respectively. This is a much finer cut than the minimum 2 to 5 microns that can be achieved in a cyclone. The centrifuge offers a better effluent quality than is needed for construction site runoff. This quality is achieved with a machine which is more expensive and of less capacity than a cyclone. The additional expense and finer size removal is justified in many commercial processes involving liquid and solid recovery of materials of significant value. It is, however, difficult to justify its use for construction site runoff. In light of this, there is little reason to further detail the characteristics of the centrifuge.

SECTION J

SEPARATION BY FILTRATION

Filters are devices which employ a filter medium to physically intercept and extract solid particles from the carrier water. The porous medium is generally either a granular bed or a perforated rigid structure. The initial interception of solids usually begins with a simple screening action, but the ultimate removal of fines also involves the establishment of complex micro forces for attracting the fines to attachment with the filter media.

By its nature the filter medium generates a resistance to water flow necessitating the presence of a differential head across the filter for the maintenance of flow. The method of providing this head leads to the commonest method of classifying filters. These are gravity, pressure, or vacuum. In addition, the nature of the configuration employed leads to a second system of classification, notably flat bed, drum, or enclosed.

Filtration alone can satisfactorily remove suspended solids from water for almost any desired use but is generally employed for removal of the finer solids and works best when the concentration of solids is not too high. Reduction of solids to a low level prior to filtration is generally recommended. Much of this is usually accomplished in a settling basin.

Of the many forms of granular filters, one of the oldest in practice is the gravity slow sand filter. This consists of a submerged bed of sand up to 4 feet deep and supported on gravel and underdrains. Raw water percolates by gravity down through the system. Rates are 2 to 3 gal./sq. ft./hr. with head losses of 2 to 3 feet. These very low rates require relatively large filter areas. Efficient operation depends on establishment of a complex biological strata in the upper layers of sand. This greatly aids in modifying and sieving many of the fine suspensions. They are cleaned after months of service by removal of the top strata. These filters do not work well with high concentrations of load or with intermittent operation and their maintenance requires either a large manual force or extensive equipment. They are not well suited for the clean-up of construction site runoff.

Rapid sand gravity filters are used in water supply treatment either for pre-treatment or for final floc removal after coagulation. Conventional rates of filtration are 60 to 120 gal./sq. ft./hr. with head losses up to 6 feet and a solids holding capacity of about 1 lb./sq. ft. They consist usually of 3 or 4 feet of fine sand supported on layers of coarse sand, gravel, and underdrains. Filtered solids build up on the surface and in the body of the filter 6 to 12 inches until the flow resistance or head loss reaches the limiting value. The filter is then cleaned by backwashing from below in an action which expands the bed and removes the deposited material. This type of filter backwash inherently leads to a gradation of filter sands with the finest at the top. In subsequent filtering action the fines promote early blockage and high head loss without efficiently utilizing the main body of the sand bed for entrapment and absorption of the fines.

In recent years there has been extensive development of alternate forms of the simple gravity rapid sand filter. These alternates operate at a higher flow rate, forcing the collected solids deep into the media to develop a greater solids holding capacity. Maintenance of a higher flow rate requires a pumped pressure system. In one of the high rate alternates, downward flow is used but with a granular bed in which the size and specific gravity of the bed material varies. Heavy garnet sands, medium silica sands, and lighter anthracite material are frequently used in these multi-media beds. During the backwash process these materials roughly stratify themselves to present several internal interfaces with the finer and lighter materials on top. This allows in-depth separation of solids with a greater efficiency, longer interval between backwashes, and reduced blocking problems. A second high-rate alternate is to use a deep (5 feet) graded multi-media filter (16 to 20 mesh) but to feed the filter from below. This presents the water to a progressively coarse-to-fine porosity with entrapment occurring in-depth in the media structure rather than at interfaces, thus providing a much larger trapping capacity (8 to 12 lbs./sq. ft). The system operates with a low volume of wash water supplemented with injected compressed air for agitation and formation of a fluidized bed and does not require filtered wash water nor storage of wash water. The total flush cycle takes about 30 minutes. It is capable of operating with turbidities which are too high for conventional or high-rate downflow sand filters (up to 1000 to 1500 ppm). In normal applications it can produce an effluent containing less than 3 ppm with sizes below 5 microns.

Upflow filters have the capability of trapping up to 50 ppm of oil with an effluent value of about 1 ppm. Under sustained exposure the oil must ultimately be washed out of the sand with surfactants. This feature could occasionally be of real value on construction sites.

Coagulants need not be used with upflow filters unless fines of less than 1 micron prevail. With alum or ferric sulphate, 10 to 40 ppm will suffice and with polyelectrolytes 1/2 to 3 ppm.

Higher rates of filter flow are continually sought for cost reduction but certain problems result. One of these comes from the fact that pressure filters will not remove extremely fine particulate or colloidal matter. This is because sand carries a charge similar to most fines and attractive forces do not develop. Hence, chemical coagulants are used as additives. The flocs which are produced by the common compounds of aluminum are relatively fragile and disintegrate with high flow rates through the bed. In later years polyelectrolytes have been used to produce a tougher floc, hence permitting use of larger sand sizes and less flow resistance. Effective removal of fines to less than one micron in size is obtained with the chemical fed at a rate of about one percent by weight of the solids rate. A 98 percent removal rate is not uncommon, including fines which cause cloudiness and color in the effluent. The coagulant can be added directly ahead of the filter, with contact taking place in the media and with no need for mixing and holding tanks as with downflow filters.

Much of the development and most of the existing plant capacity in sand filters relate to large permanent concrete structures in municipal and industrial treatment plants. However, the basic economy and dependability of sand filtration is now designed into commercial pressurized tank units which are factory fabricated, transportable, unitized, skid mounted modules, and are capable of assembly into multiples to meet any required field capacity needs. These units can be provided with manual or automated controls. Figure J-1 shows the nature of the assembly, solids-holding capacity, unit flow rates, and standard capacities typically available commercially. Module sizes are limited to those which can be readily transported by common carriers. Figure J-2 shows the size and nature of a module unit of this type of filter.

Minimum inlet pressure in a pressure filter is usually of the order of 20 psi and backwashing is recommended when the pressure differential across the filter exceeds 5 to 10 psi. Pressure pumps with their capital and operating costs are an inherent part of pressure filter systems unless available gravity gradients supply the necessary head.

Pressure filter systems with capacity in excess of a million gallons per day (700 gpm) cost less than $20,000 for each million gallons of capacity.

Field installation of a high rate filter system requires only a power supply and footings or a simple slab for mounting the factory assembled modules. This results in economy and there are few uncertainties in field costs for installation. Pressure filters are long-lived and maintenance demands are low. They do not require skilled personnel for operation. Since they are totally enclosed, they are not troubled by algae and slime growth stimulated by sunlight. They should be capable of long-time standby and intermittent operation for construction runoff.

Pressure type rapid sand filters run for longer times between backwashings than gravity filters and backwash with smaller required flow rates (≈ 9 gpm/sq. ft vs ≈ 15 gpm/sq. ft.). Upflow filters have the greatest solids handling capacity per sq. ft. and should be considered for peak flow storm use because they may permit continuous operation without backwashing for the entire period of the storm water detention and processing.

Pressure filters of smaller capacities usually involve a vertical cylindrical housing as shown in Fig. J-2 but horizontal types of tanks are preferred for large capacities. These are less portable and require more field assembly.

An interesting new granular bed filter shown in Fig. J-3 is now available in England [J-4]. Known as the Tenten filter of Simon-Hartley Ltd., it differs from conventional horizontal bed sand filters mainly in that: (a) filter flow is neither vertically up or down but instead passes in a radially inclined direction from the center of a vertical cylinder to its periphery as per Fig. J-3(a), (b) there is no discrete backwash cycle of the filter bed, instead dirty sand is continually withdrawn from the conical bottom of the cylinder and is washed and returned to the top as shown in the schematic of Fig. J-3(b).

The dirty sand is sucked from the base of the conical cylinder by a small compressed air-driven air-lift pump which constitutes the vertical return leg of the sand circuit shown in Fig. J-3(b). The simple, uncomplicated pumping device not only transports the sand vertically but provides an effective scrubbing action for separating the trapped particulates from the sand.

Gravity formation of the sloping filter face as shown in Fig. J-3(b) provides a greater filter area than a comparable horizontal bed and grades the coarser materials to the top. This arrangement provides internal flow velocities which diminish with increasing radial outward penetration of the bed. The sand is retained at the periphery of the cylinder by an outlet screen of wedge-wire construction. The arrangement permits in-depth filtering with a relatively high solids handling capacity per square foot.

Limited filtering tests comparing performance of the Tenten with conventional gravity sand filters demonstrated fairly comparable performance using biological particulate. The prime advantage of the Tenten filter is the continuous processing without cyclic downtime and the elimination of investment and space for backwash storage tanks, large volume backwash pumps, and automatic cycling controls.

Reference [J-4] gives 1976 cost data which favors the Tenten filter in comparisons with standard rapid gravity and pressure filters when employed for tertiary treatment of biological solids.

The new Tenten filter appears worthy of future consideration for the separation of solids from construction site effluents but presently available information does not as yet clarify performance with mineral solids.

A somewhat analagous radial flow, in-depth, high rate filter system is marketed in the United States by the Hydromation Filter Company of Livonia, Michigan. This unit differs from the Tenten in that it uses light-weight filter media other than sand, uses a discrete backwash cycle, is operated using high pumping pressures rather than gravity, and is primarily intended for removal of oil, grease, toxic or valuable solids from industrial waters. It is not currently offered as cost competitive with sand filters.

Granular bed pressure filters are capable of consistently delivering a high clarity effluent with a wide range of influent contaminants, including light weight organic fines as well as heavier mineral solids. They are relatively insensitive to normal fluctuations in flow and pressure. They are generally intended for continuous flow processing but do not require constant pumping to maintain filter bed integrity.

A major alternate to the granular filter is a rigid porous media consisting of a perforated plate or woven mesh for removal of solids ranging from coarse (10 mesh) to fines (down to 25 micron). A wide variety of mesh is available. It is generally of metal but as the size of the solid diminishes the metal support mesh is overlain with a finer woven fabric of cloth or plastic. The latter can provide retention down to 1 to 3 microns.

In use the porous media initially intercepts the particles which are too large to pass through the porous openings. As these openings become partly blocked, smaller particles are progressively intercepted and a cake of solids builds up on the original filter medium. This cake in turn becomes progressively finer in pore structure; the flow resistance mounts to an unacceptable level and cleaning is required. The clarity of the filter effluent is then minimum when the filter starts up clean and is maximum just before cleaning. This is true if the pressure across the cake remains low enough that the filter cake does not rupture or "break-through."

With some types of filter cake the cake porosity may be very low and high resistance or "blockage" may develop very quickly, leading to the risk of "break-through" and necessitating frequent cleaning. In many cases the filter media without "aid" can be selected to provide a good cake buildup without excessive cleaning. However, for some solids the filter cake buildup may prove unsatisfactory and the basic filter media may need "aid" to permit maintaining the flow rate and effluent clarity. This may be accomplished by introducing a foreign material into the flow which improves the porous character of the cake. This is usually necessary if the solids size distribution is too narrow, when the solids concentration is high, when the flow rate is high, or when the removal of the filter cake is difficult. Filter aids are of many forms but the most common are diatomaceous earth, fuller's earth, cellulose fibers, or asbestos fibers. Filter aids, when used, are most commonly introduced to the filter at the beginning of the filtration cycle and build up a "pre-coat" on the media. They may also be introduced into the water in controlled amounts during the buildup of the filter cake. This is known as "body feed" and leads to maintenance of a thicker and more porous filter cake and a longer time between cleanings.

At the end of a filter cycle the filter is cleaned by scraping, jetting, or backflushing and the filter aids are disposed of together with the collected solids. A new layer of pre-coat is then introduced and the cycle begins again. In some belt type machines the operation is continuous without cycles. Filters involving "pre-coat" or "body-feed" require extra facilities for storage, slurry mixing, introduction, and control. These additions incur extra cost and manual servicing. Filters of this type should generally be operated continuously to keep the cake in place until the end of the cycle. The selection of a suitable form of rigid filter and the question of whether it should operate "aided" or "unaided" is a complex one. Some guidelines based on experience are shown in Fig. J-4 which demonstrates the relation of flow rate, solids concentration, solid size, and filtering aids on effective performance.

While many common filter aids function as a simple mechanical control of the porosity of the filter cake, other types are coagulants which flocculate the finer suspended solids into larger flocs which can be retained by the filter medium.

Porous media filters come in a variety of configurations which may be broadly classified as follows:

1. Flat bed or horizontal tape or belt filters employ a wide, continuous moving belt loop of a flexible screen covered with a flexible fabric or paper filter. A horizontal top-side portion of the belt loop is submerged in a shallow pool of the influent. The fluid may be driven through the belt media by gravity alone or assisted by vacuum from below. The separated solids are continuously discharged as a relatively dry cake. The general arrangement of the machine is typified by Fig. J-5. These units may under some conditions operate with vacuums up to 10 inches of mercury and produce flow rates as high as 35 gpm per square foot. Normal operations are less than this. This type of filter is generally used in industrial fluid reclamation of a continuous nature. Large units of the type shown in Fig. J-5 are available in capacities up to 4500 gpm. They do not appear to be intended for unattended field installations and are relatively expensive per unit of filter area.

2. Stationary leaf or disc type filters consist of rectangular or round sheets of filter media compactly stacked in a flooded pressure vessel. The assembly permits the influent fluid to process through the media under pressure and then pass to discharge. Arrangements within the pressure vessel permit the media to be pre-coated, if necessary, before the filter cycle and to be scraped, jetted, vibrated, or backwashed after the cycle for cake removal. Programmed multiple units permit continuous operations. Downtime for cleaning or regenerating need not exceed about 15 minutes and cleaning can be obtained with a wash water flow of about 1/4 gal./sq. ft. The wet discharge can be pumped to disposal. Units are available in sizes up to 3000 sq. ft. of filter area.

With pre-coating, filter capacities are low, being about 1/3 to 1/2 gpm/sq. ft. Diatomaceous earth pre-coats can yield effluent with turbidity less than 1 ppm and sizes no larger than about 1 micron when body feed is used.

These units require periodic manual inspection and cleaning and are intended primarily for industrial plant installation.

3. Cartridge or tubular type filters resemble disc type units in general function, but the filter media is cylindrical in geometrical disposition rather than flat. These units also have a considerable similarity to the tubular type strainers discussed in Section F, but are more complex in that with the filter the basic mechanical strainer is usually accompanied by auxiliaries for employing filter aids, pre-coats, etc. Cartridge filters usually operate with radially inward flow when filtering.

Cartridge units may be contained in individual pressure housings or large numbers of cartridges may use a common pressure housing as shown in Fig. J-6. The cylinders may be of perforated wall or wound-wire metal construction. The cylinder wall may serve as the only filter media or it may serve merely as under drainage support for slip-on socks of finer weave. These filters may be used for separations ranging from a coarse 10 mesh down to 1 micron with fine fabrics. These filters generally start with about 5 psi differential pressure and rise to 35 psi before automatically cycling into backwash. High solids contents call for frequent cycling and these filters are not usually intended for high loadings. Multiple units permit alternate cycling to provide continuous operation. The flow capacity per cylinder may be as much as 250 to 300 gpm with assemblies totalling up to 3000 gpm. Some tubular types are operated with pre-coating in much the same way as leaf filters. The filters are not generally intended for the high flow rates and the high solids loads that may be present with construction site runoff.

4. The rotary vacuum filter consists of a large drum or stacked discs rotating about a horizontal axis with the lower portion of the rotor submerged in a tray of the influent water. A vacuum applied to the compartmented interior of the drum or disc assembly draws the water through the filter medium, enclosing the exterior of the drum or disc. The disc form of rotor is lower in cost and occupies only a quarter to a third of the floor space of a drum form, but it is much more constrained in its operation. It is, therefore, much less common than the more versatile drum form. The drum type generally takes the form shown in Fig. J-7.

During the course of a slow revolution of the compartmented drum (generally 1/10 to 1/4 RPM but ranging up to 3 RPM) three separate actions occur. The first involves a buildup of a solids cake on the filter surface in the course of the submerged passage through the tray. This is followed by passage through the air during which the cake is dewatered and dried. In the final action, just before recycling, the vacuum is released and the cake is peeled from the drum and routed to disposal. The filtering and drying portions of the processing cycle are relatively straight forward and, with selection of a suitable filter cloth, submergence depth, and rate of rotation, a satisfactory filter cake can generally be built up with relatively high feed rates. The more complex judgments relate to the methods necessary to the removal of the filter cake from the drum. Since the cake may vary greatly in its thickness, density, porosity, strength, stickiness, and other factors, a variety of devices have been evolved to achieve effective removal of the cake. Five common methods of removal are depicted in Fig. J-8.

A system which works well with moderate to low solids concentrations uses a layer of endless strings around the drum at spacings ranging from 1/4 to 1 inch. This system is shown in Fig. J-7 and Fig. J-8(a). The strings serve to peel even a thin layer of materials such as clay from the filter cloth and feed it into a discharge hopper. Because there are no scraper knives or other mechanical wear contacts on the filter cloth, thin, delicate, high flow fabrics can be used with simple fabric make-up and attachment provisions.

The arrangement of Fig. J-8(b) uses a knife for shaving the cake from the filter cloth. The removal is aided by blowing compressed air from beneath the cloth. With some solids, the knife may be set to leave a thin layer of solids on the drum, enhancing the cloth as a filter medium. This system also works well with moderate to low solids concentrations.

The roller and belt arrangements of Figs. J-8(c) and J-8(d) are useful with mixes of low solids concentration or those forming a weak cake and may permit higher rates of filtration.

The pre-coat knife system shown in Fig. J-8(e) can be used where cake removal proves difficult by other means or where solid concentration is low or good filtrate clarity is needed. The pre-coat is built up on the drum fabric using a suitable pre-coat slurry in an operation conducted prior to normal filtration. This buildup may be up to as much as six inches thick and may take about an hour to form, using a high drum rate and low tray submergence to achieve thin layers. The pre-coat may consist of diatomaceous earth, perlite, calcium sulphate, wood flour, or fly-ash to yield a highly permeable, low cost, filter cake which can be shaved in very thin slices.

For good economy the pre-coat filter should operate with the highest practical submergence and the lowest possible knife advance rate. With suitable control of drum speed and knife advance, a single pre-coat can operate for several days.

A further alternate method of removing the filter cake is provided by the Trommel belt filter [J-10]. This is similar in generalities to the drum type vacuum filter of Fig. J-7. However, the filter media is standard newspaper which is continually fed into the machine from a stock roll and exits from the machine as a disposable continuous sheet conveying the filter cake. The process, which is shown schematically in Fig. J-9, is simpler, higher rate and more manageable than the removal methods of Fig. J-8 but requires the use of an expendable filter media.

Drum filters are available with a wide variety of manual and fully automated controls. These filters have been employed in a wide variety of services and have established that they are relatively simple, robust, versatile, and of acceptable cost per unit area for many applications.

The basic filter must have auxiliaries to complete an operating installation. These consist of a vacuum pump, a water removal pump, a cake handling disposal system, and a slurry preparation and feed system if pre-coat is to be used.

Drum filters are commercially available in diameters up to 12 feet with lengths to 24 feet having up to 1200 square feet of filter and with solid removal rates ranging up to hundreds of pounds per hour per square foot, with influent solids contents ranging up to 50 percent by weight, and with influent rates of about 3 gal./sq. ft./min. They usually require a vacuum of 15 to 20 inches of mercury and involve air handling of 2 to 5 cu. ft./sq. ft./min. (air volume under vacuum condition). In addition to the energy requirements for vacuum pumping, the filtrate must be removed from the filter with a pump working against a head which is at least equal to the operating vacuum.

Uncoated vacuum drum filters work in an influent solids content ranging from about 0.1 to 50 percent by weight. Coated filters usually work in the range from 0.01 to 0.10 percent. They are usually employed for removal of solids in the size range from 0.5 to 500 microns, with the pre-coat types removing the smaller sizes.

These units might be considered for removal of fines in some construction site problems, but in general they are relatively larger in size and cost and require more attention than alternate systems.

Of the several types of filters discussed, the high rate, upflow, granular pressure filter appears to offer the best complement to a settling basin for achieving removal of solids under construction site conditions. They can achieve removal down to 2 micron size with effective flow rates and can remove even finer materials with the addition of chemical coagulants. However, because of the need for auxiliary equipment and for skilled personnel for determining and maintaining chemical treatment, it is suggested that this be eliminated for all but exceptional field needs.

LIST OF REFERENCES

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[J-2] U.S. Filter Corporation, Bulletin L-119, Whittier, California.

[J-3] U.S. Filter Corporation, Drawing 900-024, Whittier, California, 197

[J-4] Reprinted from "Development of a Continuous Inclined Sand Bed Filter," Filtration and Separation, March/April, 1976, by Allanson, J.T. and Austin, E.P., with permission of Uplands Press Limited, 1 Katharine Street, Croydon, England.

[J-5] Hoffman Filtration Systems, Liquid Filtration Methods and Related Equipment, Bulletin FB-111, Syracuse, New York, 1971.

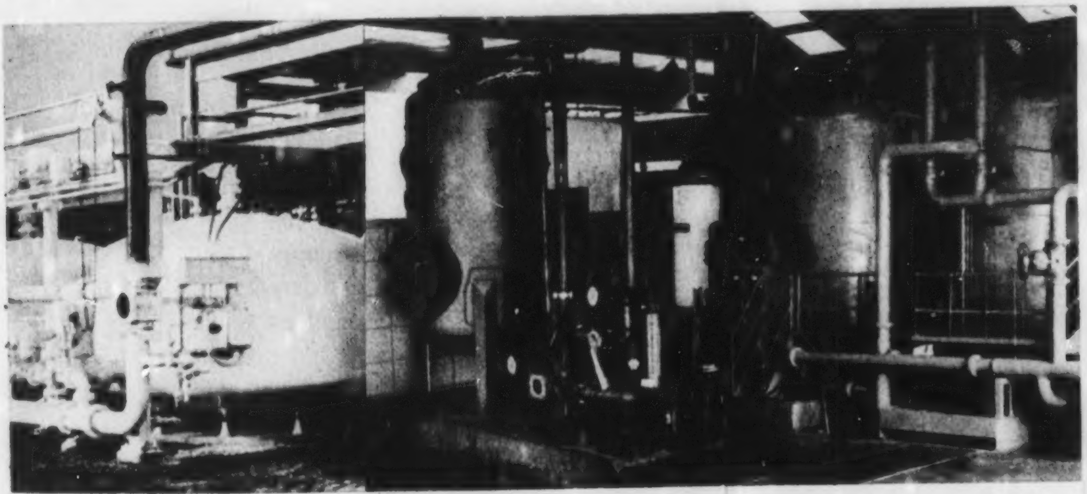
[J-6] Hoffman Filtration Systems, Hoffman Vacuumatic Liquid Filtration Systems, Bulletin FB-1094, Syracuse, New York, 1973.

[J-7] U.S. Filter Corporation, Auto-Shok Tubular Backwash Filters, Catalog Sheet TD 607-C, Whittier, California.

[J-8] Ametek Inc., Rotary Vacuum Drum Filters, Catalog FC-072, East Moline, Illinois, 1974.

[J-9] Reprinted from "Vacuum Filters", Process Engineering Technique Evaluation Filtration, 1969, by Bosley, R., with permission of Morgan-Grampian Ltd.

[J-10] Anon., Trommel Rotary Vacuum Drum Filter, Bulletin TR-73, Technical Fabricators, Inc., Piscataway, New Jersey.



CONVENTIONAL DOWNFLOW

This granular-bed pressure filter is extremely effective in liquid-solid separation at flow rates up to 5 gpm per sq ft of filter area. With properly selected media, granular as well as gelatinous suspended matter is filtered without a rapid differential pressure build-up. Typical filter media consists of selected silica sand, anthracite coal, garnet or any combination of these.

The solids-holding capacity will range from ½ to 1½ pounds per sq ft of filter area, depending on the physical characteristics of solids removed.

Filters are furnished complete with internals and media. Piping, valves and controls for automated operation are also available.

CLEANING The filter bed is expanded by a high rate of filtered water flowing upward through the bed. All solids are carried out the top of the filter. Cleaning is accomplished in a very short time, generally less than five minutes.

APPLICATIONS For removal of turbidity, softening process precipitates, oxidized iron and manganese, algae and microrganisms from potable and process water . . . removal of organic matter from cooling systems and particulate matter from fluids such as brine, caustics, acids and plating solutions.

CAPACITY Standard units are rated from 10 to 2,500 gpm for a single filter. Multiple units are available complete with interconnection headers and valves for larger capacities.

HIGH-RATE DOWNFLOW

Unlike conventional downflow filters, this unit operates at high-flow rates of 12 to 20 gpm per sq ft of area. A scientifically-engineered distribution system keeps close control of velocity and hydraulic balance within the filter, allowing operation at these high rates without disturbing the media.

By filtering at rates above 12 gpm per sq ft, the collected solids are forced deep into the media, producing a depth filtration and longer cycles. Solids-holding capacity ranges from 1 to 4 pounds per sq ft of filter area, depending on the physical characteristics of solids removed.

Filter media is uniform in size, but types may vary or even be combined for maximum efficiency. Typical types are Silica sand, garnet and anthracite coal.

CLEANING The filter bed is expanded by an upward flow from an underdrain system. Entrained solids are scrubbed and released from the sand bed and out the top. Cleaning is accomplished in less than five minutes.

APPLICATIONS Typical uses range from sea water and cooling water systems to oil-field brine where oil is removed as well as suspended solids. Also, industrial waste water, tertiary sewage treatment, mill scale and color removal.

CAPACITY Standard size units are rated from 60 gpm to 28,000 gpm. Multiple units can be furnished complete with interconnecting headers and valves. Full automation is also available.

HIGH-RATE UPFLOW

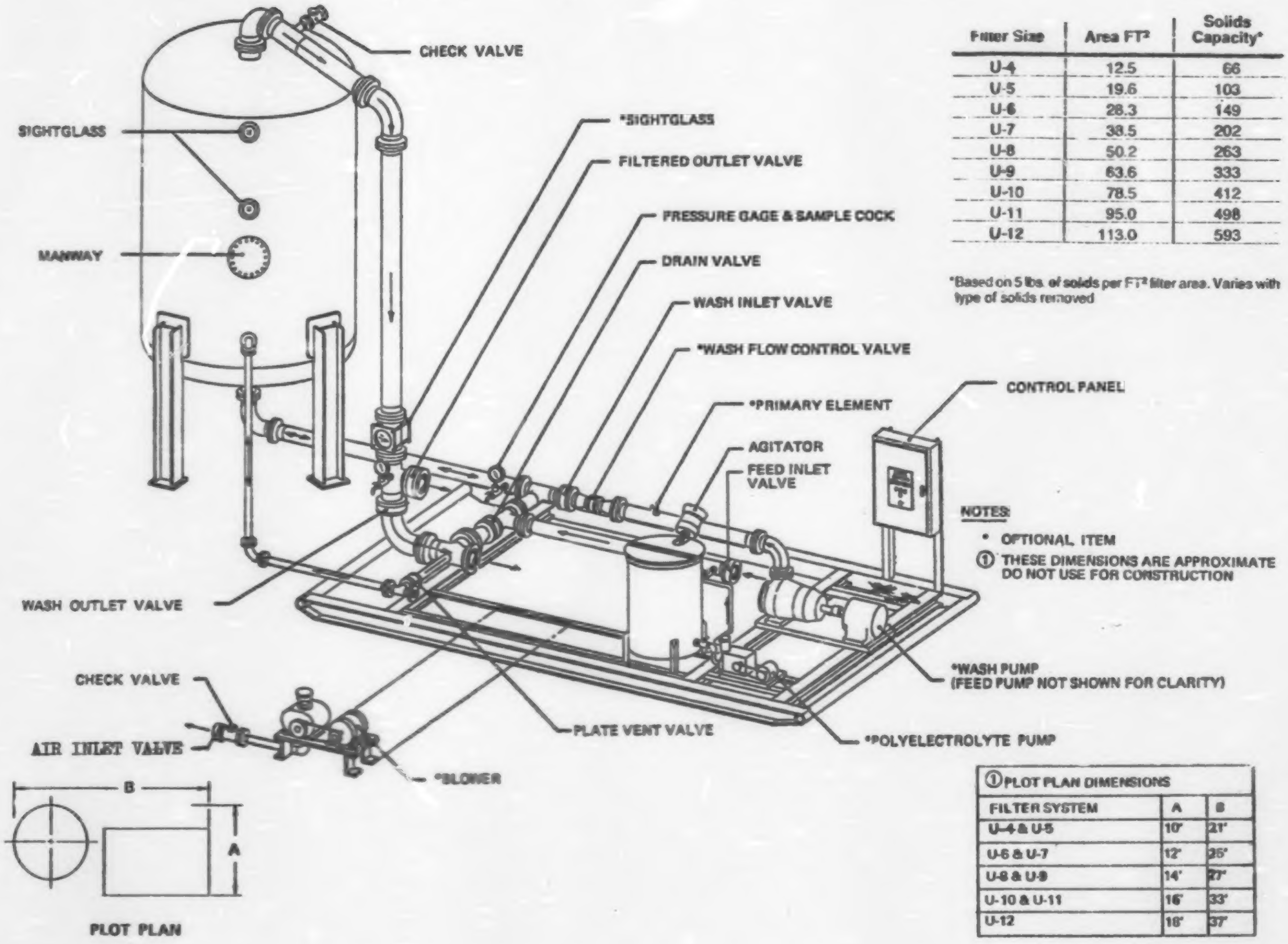
A high performance upflow sand filter system. Ideally suited for applications where high turbidities make conventional sand filters impractical. Filtering rates of 6-12 gpm per sq ft surface areas result in significant savings in initial equipment cost and floor space required. The entire bed depth is utilized to trap solids with the fine top layer serving as final cleanup. This allows a suspended-solids capacity of up to 10 pounds per sq ft surface area, depending on the physical characteristics of the solids removed.

CLEANING The bed is expanded by air agitation prior to backwashing, assuring a scrubbing of the bed for maximum cleaning efficiency. This feature allows backwashing with raw water for complete removal of bed turbidity without loss of filtered water.

TYPICAL APPLICATIONS Ideal for a wide range of service such as water, sea water or produced brine for deep well injection; surface water upgrading for plant or process use; waste water clean-up to meet pollution control standards.

CAPACITY Standard size units are rated from 150 gpm to over 1300 gpm per single filter. Multiple units, complete with all accessories for manual, semi-automatic and fully automatic operation can be supplied to meet any requirement.

Fig. J-1. Characteristics of various modern granular-bed pressure filters (From Ref. [J-1])

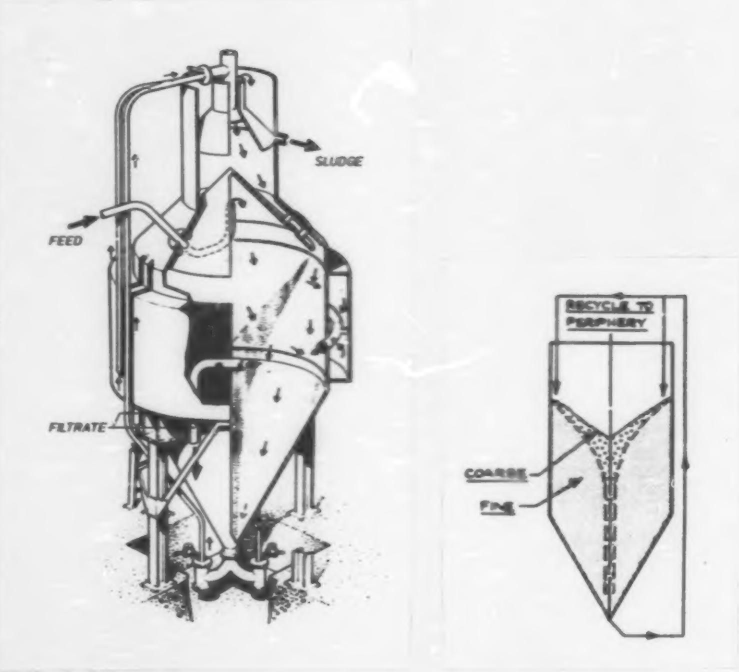

CHECK VALVE
SIGHTGLASS
MANWAY
*SIGHTGLASS
FILTERED OUTLET VALVE
PRESSURE GAGE & SAMPLE COCK
DRAIN VALVE
WASH INLET VALVE
*WASH FLOW CONTROL VALVE
*PRIMARY ELEMENT
AGITATOR
FEED INLET VALVE
CONTROL PANEL
NOTES:
* OPTIONAL ITEM
① THESE DIMENSIONS ARE APPROXIMATE DO NOT USE FOR CONSTRUCTION
WASH OUTLET VALVE
*WASH PUMP
(FEED PUMP NOT SHOWN FOR CLARITY)
CHECK VALVE
AIR INLET VALVE
*BLOWER
PLATE VENT VALVE
*POLYELECTROLYTE PUMP
B
A
PLOT PLAN

Filter Size	Area FT²	Solids Capacity*
U-4	12.5	66
U-5	19.6	103
U-6	28.3	149
U-7	38.5	202
U-8	50.2	263
U-9	63.6	333
U-10	78.5	412
U-11	95.0	498
U-12	113.0	593

*Based on 5 lbs. of solids per FT² filter area. Varies with type of solids removed

① PLOT PLAN DIMENSIONS		
FILTER SYSTEM	A	B
U-4 & U-5	10'	21'
U-6 & U-7	12'	25'
U-8 & U-9	14'	27'
U-10 & U-11	16'	33'
U-12	18'	37'

Fig. J-2. Make-up and characteristics of a high-rate, upflow, granular bed, pressure filter (From Refs. [J-2, J-3])


SLUDGE
FEED
FILTRATE
RECYCLE TO PERIPHERY
COARSE
FINE

(J-3a) (J-3b)

Fig J-3. The Tenten inclined sand bed filter (From Ref. [J-4])

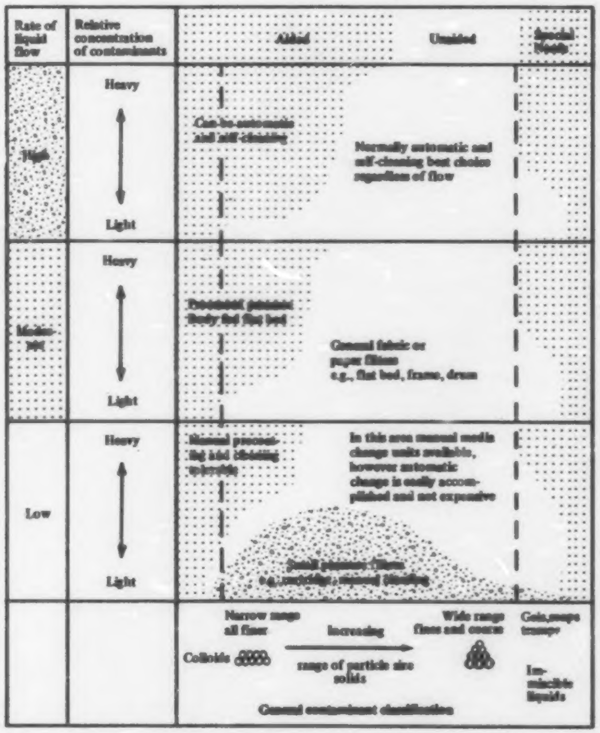

Rate of liquid flow
Relative concentration of contaminants
Aided
Unaided
Special Needs
High
Medium
Low
Heavy
Light
Can be automatic and self-cleaning
Normally automatic and self-cleaning best choice regardless of flow
Precoated pressure Body fed flat bed
General fabric or paper filters e.g., flat bed, frame, drum
Manual processing and cleaning tolerable
In this area manual media change units available, however automatic change is easily accomplished and not expensive
Small pressure filters e.g., cartridge, manual cleaning
Narrow range all fines
Increasing
Wide range fines and coarse
Colloids
range of particle size solids
Immiscible liquids
General contaminant classification

Fig. J-4. A guide to filter operating conditions requiring filter aids (From Ref. [J-5])

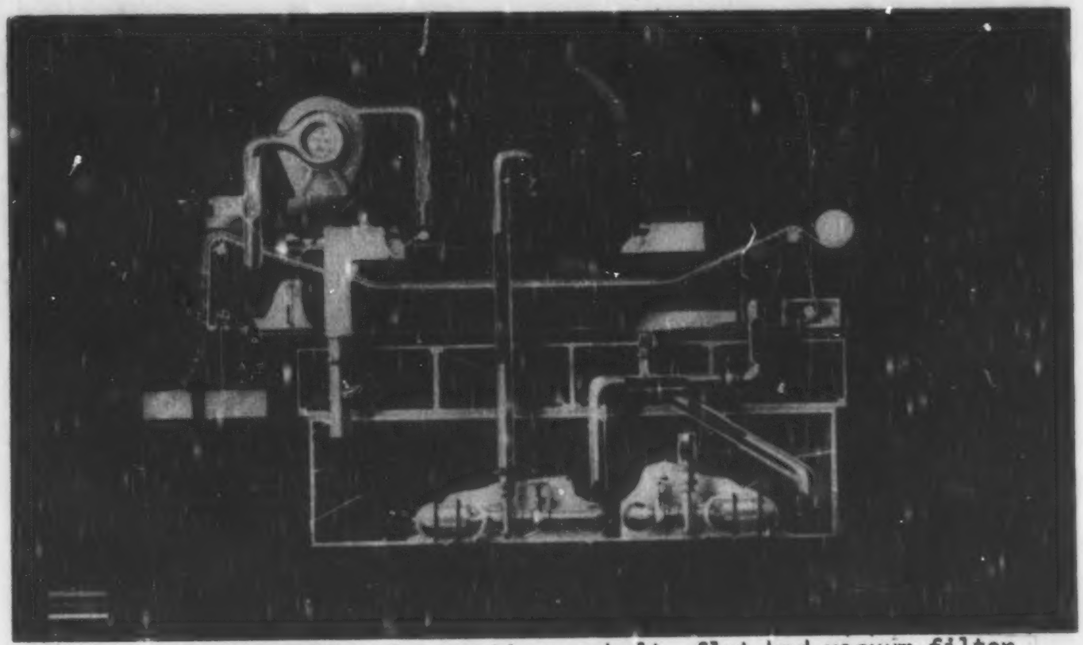


Fig. J-5. Assembly of a continuous belt, flat-bed vacuum filter (From Ref. [J-6])

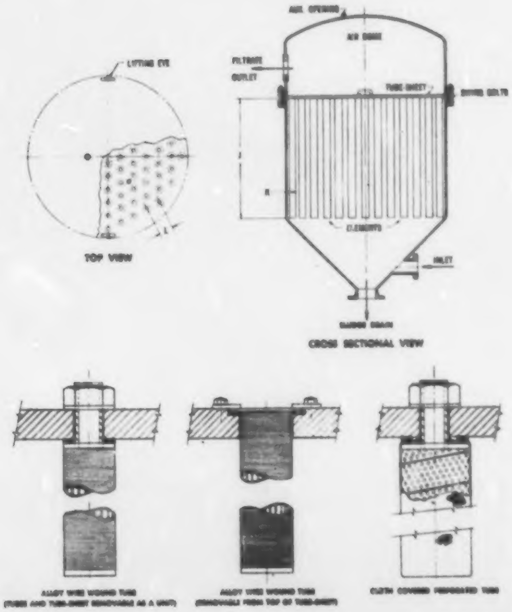

LIFTING EYE
TOP VIEW
AIR DOME
FILTRATE OUTLET
TUBE SHEET
SWING BOLTS
ELEMENTS
INLET
SLUDGE DRAIN
CROSS SECTIONAL VIEW
ALLOY WIRE WOUND TUBE (TUBES AND TUBE-SHEET REMOVABLE AS A UNIT)
ALLOY WIRE WOUND TUBE (REMOVABLE FROM TOP OF TUBE-SHEET)
CLOTH COVERED PERFORATED TUBE

Fig. J-6. Cartridge filter unit - multiple type (From Ref. [J-7])

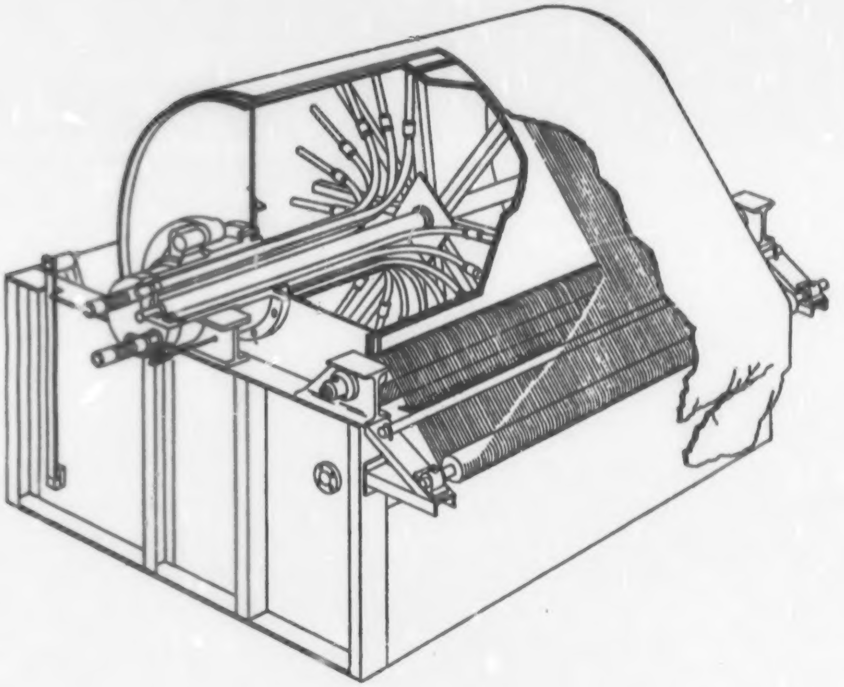


Fig. J-7. A drum type vacuum filter with string discharge (From Ref. [J-8])

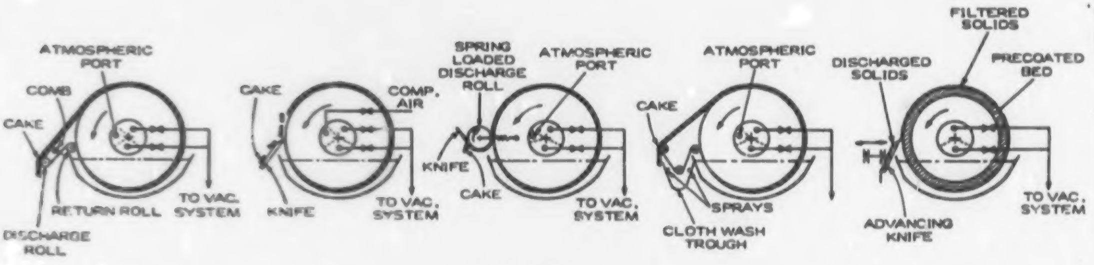

ATMOSPHERIC PORT
COMB
CAKE
RETURN ROLL
TO VAC. SYSTEM
DISCHARGE ROLL
(a)
CAKE
COMP. AIR
KNIFE
TO VAC. SYSTEM
(b)
SPRING LOADED DISCHARGE ROLL
ATMOSPHERIC PORT
KNIFE
CAKE
TO VAC. SYSTEM
(c)
ATMOSPHERIC PORT
CAKE
SPRAYS
CLOTH WASH TROUGH
(d)
FILTERED SOLIDS
DISCHARGED SOLIDS
PRECOATED BED
TO VAC. SYSTEM
ADVANCING KNIFE
(e)

Fig. J-8. Alternate methods of removing filter cake (From Ref. [J-9])

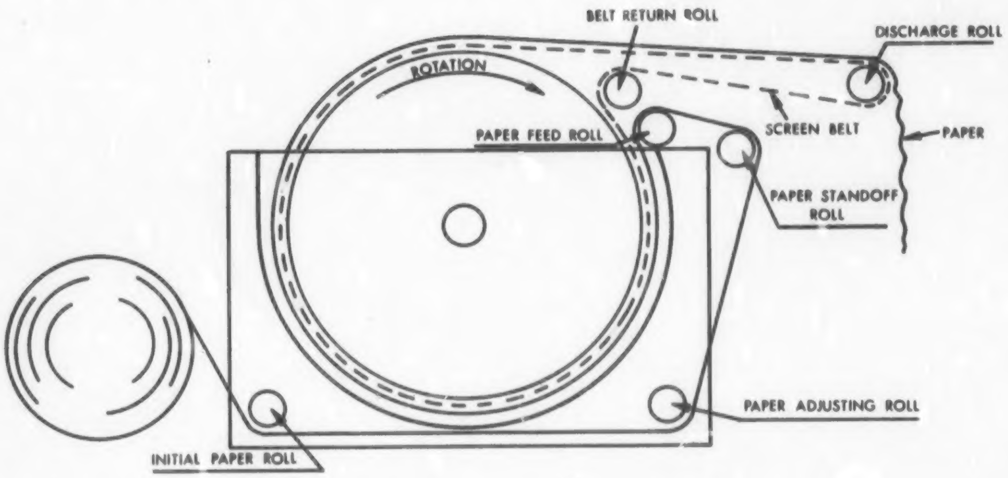

BELT RETURN ROLL
DISCHARGE ROLL
ROTATION
SCREEN BELT
PAPER
PAPER FEED ROLL
PAPER STANDOFF ROLL
PAPER ADJUSTING ROLL
INITIAL PAPER ROLL

Fig. J-9. The Trommel drum type vacuum filter with newspaper filter media (From Bull. TR-73, Technical Fabricators, Inc.)

SECTION K

COAGULANTS AND FLOCCULATION

Mineral solids larger than about 0.2 microns diameter settle under the gravitational influence at a rate which permits practical separation in simple settling basins. However, mineral solids smaller than 0.2 microns and other solids with suitable values of size and weight may remain in stable colloidal suspension in water for an indefinite period. The separation of these particles requires an understanding of the destabilization mechanism. The efficiency of the settling process can be increased by the addition of coagulation. In this process, finely divided particles that cause turbidity and color are combined by chemical means into masses large enough to settle rapidly. This process also serves to agglomerate the particles to make the water more filtrable.

The stability of a particle in colloidal suspension is due to inherent turbulence and brownian diffusion together with negative electrical charges which develop at the particle-water interface. The charge differential is partially balanced by counter ions in the solution which are attracted to the charged surface and build up a compact layer around the particle.

The colloidal particles, which are in a constant state of motion, either repel each other on approach and remain in stable suspension or they may collide, aggregate, and destabilize their suspension. The course of events which may lead to destabilization is a complex play of forces in which an added coagulant provides the critical influence.

Both the particle and the water have a wide variety of individual properties and combinations of their properties which may critically influence the suspension. Four possible methods of particle destabilization are generally recognized. These include: (1) compression of the electrical double layer which surrounds the particle, (2) adsorption and charge neutralization, (3) enmeshment in a precipitate which is caused to form, and (4) adsorption and interparticle bridging. It is generally rare if only one of these four mechanisms are involved in the destabilization. Usually two or more mechanisms occur simultaneously in a complex balance.

For action by double-layer compression, counter ions must be added to the solution to compress the electric double layer and allow the strong localized aggregating forces to dominate over repulsive forces.

For adsorption and charge neutralization, a normally large ionized coagulant is adsorbed on the colloid surface, thus creating a larger neutrally charged particle. This causes the adverse effects of the normal electric double layer to be eliminated and coagulation may proceed. However, coagulant overdosing is possible and may create a charge reversal and restabilization of the suspension. This may occur when aluminum and ferric inorganic salts are used with colloidal silica particles.

For colloidal removal by enmeshment, metal salts or metal oxides are added to the water in sufficient quantity that complex gelatinous precipitates or hydroxides or carbonates rapidly form and settle. The colloids are enmeshed in the precipitated coagulum as it forms and as it settles. The resulting volume of sludge is substantially greater than the original solids. Aluminum sulphate is a highly soluble, commonly used coagulant and reacts with either natural or added alkalinity in a raw water to produce an aluminum hydroxide floc. Inorganic ferric and aluminum salts are frequently used for this purpose.

For adsorption and interparticle bridging, certain synthetic organic polymers are used. These in water have a polyelectrolyte molecule which is adsorbed into the colloid's surface so that it extends out into the water and can adsorb on a second colloidal particle forming an interparticle bridge. This progressively leads to a destabilized, loose, porous, floc whose make-up is largely the natural suspended solids. If the colloidal particle concentration is too low, the extended molecule may adsorb and restabilize the original particle. In many instances the positively charged cationic polyelectrolyte must be supplemented with so-called coagulant aids which are nonionic or anionic in charge in order to make a better floc with more rapid and complete settling characteristics. Activated silica in a dose of 2 to 5 ppm is sometimes used for this purpose. Flocculation is thus dependent on coagulant dose, colloid concentration, transport or shear phenomena, and solution characteristics. Flocs formed by this coagulant procedure greatly enhance subsequent filtration but may pose a problem in cake volume.

The hydration characteristics of the colloidal particle can also have a strong influence on the coagulation and flocculation process. With some particles and with inorganic coagulants such as alum, a change in the pH or acidity of the water has a marked effect. In some extreme cases flocculation cannot be achieved without prior pH control upon the hydration, and thus on coagulant dosage. Most waters coagulate best with alum when the pH is in a range from 6.1 to 6.8. If the alkilinity is insufficient, it may be necessary to add an alkali such as soda ash or lime. In other particle types, and generally with a properly selected organic polycationic polymer, the water pH value has little effect. There may be wide differences between various types of clay, quartz, and silica colloidal particles in this regard.

Coagulation and flocculation are time dependent, with rates depending on the coagulant, the colloid, and the solution characterisitics. The latter item may include the temperature, solids concentration, and state of agitation. This means that use of coagulants may be wholly ineffective if suitable residence time and agitation are not available in the system, and if the temperature is too low. This also means that there is a possibility that a destabilizing condition may occur for one concentration of solids, with stabilization occurring with either an increase or decrease in concentration.

It should be apparent from the foregoing that the use of coagulants and flocculation for solids separation involves a complex relation with no available generalized determination of the best coagulant and dosage to employ in a given case. Trial and error with various coagulants appears to have been and still remains the most practical approach for the selection of a coagulant. Trials generally employ a jar test in which the water sample and the coagulant are suitably agitated and then observed in a settling sequence. The suspension sample in a jar of about one quart size is observed in terms of turbidity improvement as a function of detention time. Jar test findings must be tempered by the facts relating to the way in which the coagulant would be introduced in the field, the level of agitation which might prevail, and the time of detention that might be available for coagulant dispersal and ultimate settle-out.

Aluminum sulphate (alum), in a quantity of about 25 ppm, is widely used as a general purpose coagulant in water supply practice, and works well with a wide variety of solids unless the pH value of the solution is in an unusual range. Sodium aluminate and ferrous sulphate are employed in some cases. Many of the more modern polyelectrolytes can work well with only a small fraction of the dosage needed for alum. They are, however, much more expensive per unit weight than alum, and sometimes pose more sensitivity to the conditions of use.

Coagulants are generally added to the water prior to settling to enhance the settling. They may instead be added just prior to filtration, in which case considerable savings in chemicals and equipment may be possible.

If coagulation or flocculation are being investigated as a means of solids removal for a particular site, it is recommended that coagulant suppliers be consulted for the most economic selection under the conditions to prevail.

The separation of solids from water by the use of coagulants and flocculation is usually employed in treatment plants where trained personnel can monitor and adjust for changes in influent quantity and quality. Under these conditions, the clarification that can be obtained through sedimentation or filtration processes may result in truly spectacular increases in performance. There is, however, considerable doubt that a simple, unattended system with a widely varying non-perrenial flow can effectively employ chemical coagulation. Sophisticated sensors and controls could be applied but with costs which probably would be unacceptable.

LIST OF REFERENCES

[K-1] Nalco Chemical Company, Water Clarification Questions and Answers, Bulletin 40, September 1972.

[K-2] Robinson, C.N., "Polyelectrolytes as Primary Coagulants for Potable Water Systems, Journal, American Water Works Association, April 1974, pp. 252-257.

[K-3] Beardsley, J.A., "Use of Polymers in Municipal Water Treatment," Journal, American Water Works Association, January 1973, pp. 85-90.

SECTION L

SEPARATION BY ELECTROPHORESIS

The ability of an electric field to attract solid particles by virtue of their surface charge is known to almost everyone who has observed the attraction of lint or bits of paper by an electrically charged comb or other plastic object. This phenomena has been widely applied in industry and the home in electrostatic precipitators for removal of dust from the air.

It is not surprising to find that this phenomena has a counterpart in liquids. An electric current flowing in a liquid can cause solid particles to migrate along the current in a direction determined by their surface charge. Many references can be found for the separation of solid from liquids or for the measurement of particle charge from a measurement of particle mobility. The number of references to electrophoresis as a phenomena adaptable to a number of specialized applications are too numerous to cite in any comprehensive way [L-1].

No specific commercial application or equipment for electrophoretic purification of water has been found except for that relating to the inverse problem of dewatering of soils. The literature survey has included the last ten years of the Applied Science and Technology Index and the Engineering Index. Articles have been examined for associative reference for the last ten years in the Journal of the Sanitary Engineering Division of the ASCE, Transactions of the American Society of Agricultural Engineers, Water and Waste Engineering, Journal of the American Water Works Association, and Filtration and Separation. Two references have been found whose objective is the use of electrophoresis for water purification on a commercial scale. Only laboratory models have been used to arrive at the projections. The information given here is based on these Refs. [L-2, L-3].

The two references cited describe systems in which an electric field is set up in a liquid by two parallel plate-screen electrodes immersed in the liquid to be processed. As the liquid moves through the space between the electrodes, solid particles migrate toward the electrodes and flow toward the bottom because of the increased concentration of heavier solids. Cleared liquid can be removed at one point and concentrated solids at another. Variations have included porous electrodes in which the particles are held away from the electrode by the field and clear liquid passes through, leaving the concentrated solids to settle in the chamber without attaching to the electrode. Membranes are usually required to isolate the electrodes from disturbing the particle motion in the migrating solids region of the chambers. Gas given off at the electrode can generate liquid velocities in the chamber which disturb the separating action.

Reference [L-2] reports a system in which the electric field is used to prevent the clogging of filters, thereby increasing significantly the time between filter backwashing.

The greatest disadvantage of the system in large scale application is the high electric power consumption when the electrical conductivity of the liquid is high, which is usually the case where dissolved salts are present. Storm water would usually be regarded as having low conductivity except perhaps in the northeastern United States where even rainwater has a high content of dissolved sulfur dioxide and nitrogen oxide. Figure L-1, taken from Ref. [L-2], gives a means of estimating power requirements based on the electrical conductivity of the liquid. The line labeled "0.30P" is based on laboratory measurements. The line labeled "0.90P" is an estimate for a prototype. The P means "power efficiency;" it was not precisely defined in the article, but it serves nevertheless as a relative measure.

Storm water runoff from construction sites probably corresponds to the rainwater sources shown on Fig. L-1. This is a favorable condition in that a high electric field can be set up with least power. A power estimate is given in Ref. [L-2] as 62 kilowatt hours per 1000 gallons and a flow rate of 1.0 gallon per hours per square foot of so-called filter. Reference [L-3] gives a much lower power estimate of kilowatt hours per 1000 gallons in an experimental set-up with deionized water and a clay suspension. Concentrations of clay up to 105 ppmw were reported. A surface scatter turbidimeter was used as a monitor.

Some insight into the use of electrophoresis for storm water purification stems from the following hypothetical problems.

The rainfall in the Upper Midwest is on the average approximately 22 inches per year on a small (1000' x 1000') or 10^6 square feet construction site. This would amount to 13,713,333 gallons per year. With 8,760 hours in a year and 1.9 gallons per hour per square foot of filter, 824 feet of filter would be required. It would seem possible to devise a portable processing system for these dimensions. The processing rate of 1,567 gallons per hour would require approximately 100 kilowatt hours (97.185 kw) [L-2] and 850,206 kilowatt hours for the one year period. At a rate of 4 cents per kilowatt hour, the yearly electric cost would be $34,000. In addition, supplies and maintenance are needed which could be three times this value.

The flow rates for peak storms obviously require a storage facility to minimize the size of plant to be used.

The recommendation which seems evident in the literature is that the electrophoresis method might be an effective means of purifying storm waters, provided it could be verified first in a pilot plant study. All work to date has been on small laboratory set-ups which may not scale up to large sizes. Reference [L-3] proposed that with suitable electrodes, flocculants are generated by the disintegration of the electrodes and added to the water. These flocculants materially speeded capture and removal of solids.

It must be emphasized that even if the costs projected here are favorable, they are projections from laboratory model studies and should not be used as a basis of action except for a demonstration processing plant.

Electrophoresis at this time does not appear to be a practical solution to the solids separation problem of construction runoff even though it has unique properties for removing ultrafines, including color.

LIST OF REFERENCES

[L-1] Bier, Milan, Electrophoresis Theory Methods and Applications, Academic Press Inc., New York, New York, 1959.

[L-2] Reprinted from "Water Purification by Forced-Flow Electrophoresis", Journal of Sanitary Engineering Division, December 1965, by Cooper, F.G., Mees, Q.M., and Bier, M., with permission of the American Society of Civil Engineers.

[L-3] Lyle, W.M., Hiler, E.A., "Electrophoretic and Electrochemical Water Purification Systems", Transactions of American Society of Agricultural Engineers, Vol. 15, No. 3, May-June 1972, pp. 580-583.

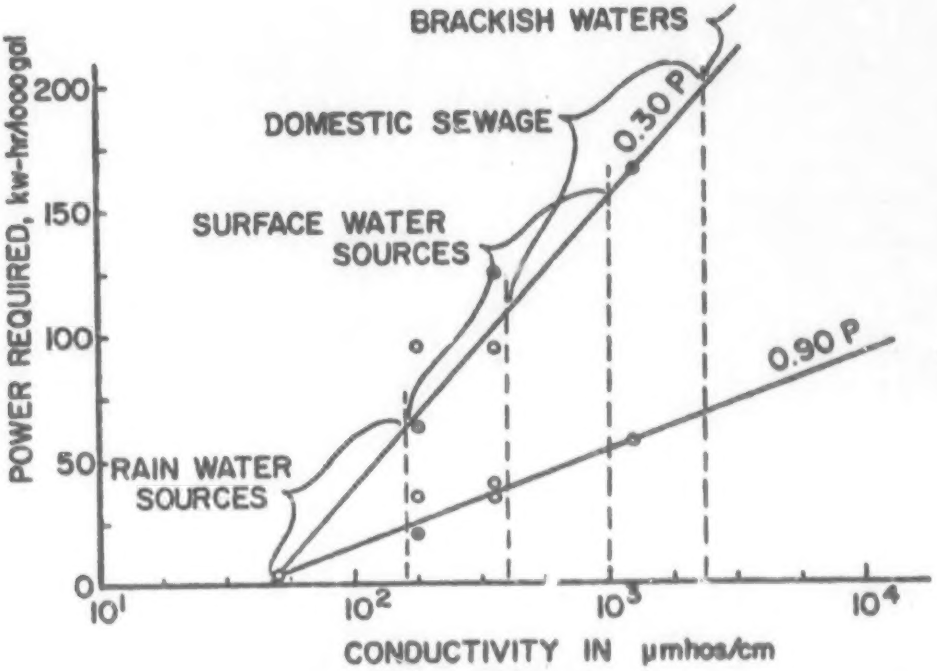


Fig. L-1. Power required for colloid separation by forced-flow electrophoresis as a function of conductivity (From Ref. [L-2])

SECTION M

SUMMARY EVALUATIONS AND RECOMMENDATIONS

EVALUATION OF THE SEDIMENT LOAD

The first steps in establishing a corrective procedure for soil-carrying runoff are estimation of the maximum rate of water runoff without and with a good debris basin installed near the site exit, and estimation of the annual yield of soil in tons entering and leaving a good debris basin near the site exit. Procedures for determining the water runoff and solids yield are discussed in Section C, including consideration of the benefits of using on-site erosion control. Section C also gives references for establishing a suitable debris basin. Figure D-1 (from Section D) can then be used to approximate the percentage of the solids yield from the site which will pass through the basin.

Procedures for determining the representative solids size distribution for the site are given in Section B and some typical examples are shown in Fig. M-1. If representative samples from the construction site are similarly tested and plotted, the plotting together with the percentage yield from the basin can serve to give some idea of the material to be contained in the basin effluent. These findings can be tempered with the data of Fig. C-3 to give some concept of the effluent sizes to be treated when processing the basin withdrawals occurring after cessation of basin inflow.

It is probable that if a suitable debris basin is used, all sizes coarser than clay and a medium silt will be removed from the runoff for the design storm condition. This will normally impose only the clay and silt solids on the auxiliary separation equipment. This involves sizes from about 0.2 to 60 microns. In most cases sizes less than 10 microns will probably not be important unless present in substantial quantity or high visual quality standards are imposed. A better definition of the acceptable limiting relations between sediment size and concentration is needed.

The solid sizes present in debris basin effluent are also in need of evaluation for basin inflow rates which are larger than those of the design storm. Major storms will occasionally increase solids in the debris basin effluent to a value which exceeds the removal capacity of available separation facilities. These overload conditions are in need of clearer evaluation.

EVALUATION OF SEDIMENT SEPARATION EQUIPMENT

The capabilities of the more effective modern commercial equipment available for the separation of solids from water have been discussed in the body of this report. The information therein has been graphically summarized in Fig. M-2 with regard to the important sediment size capabilities with which these facilities operate best. The plotting has been arranged on the same size base as that commonly employed in general studies of sediment size analysis as typified in Fig. M-1. Additional information on equipment capabilities may also be gleaned from the tabular summary of Fig. M-3 relating to standard equipment available for the clarification of industrial effluents.

A curve of the type of Fig. M-1 for representative soils from the site when compared with Figs. M-2 and M-3 will serve to narrow the selection of the type of auxiliary equipment. Unfortunately, this size selection is by no means precise because effective operation of the equipment is also critically dependent on the concentration of solids being delivered to the equipment (see Fig. M-3). It must also be recognized that much of the available information on the performance of these devices relates to industrial experience with solids in which shape and specific gravity of the solid may be markedly different from the mineral solids dominant in construction site runoff. It may, therefore, be necessary to run specific tests to better define these limits for construction site conditions.

Because of the wide range of field conditions that may exist in construction practice and because of the wide ranging capabilities and sensitivities of the available corrective equipment, generalized recommendations are difficult to make. In consequence, a number of separate recommendations are made for specific facilities as follows:

1. Simple sieves probably have little place in construction runoff treatment under most conditions. The capacity of individual units is small if the smaller sizes (0.2 to 0.5 mm) of their solids separation capabilities are employed. They require an operating energy head of 10 feet or more. Sieves have been described in Section F.

2. Microstrainers should be given consideration where the site effluent will contain most of its solids in a size range above 25 to 30 microns. They may serve in such cases where discharges are small and they may replace the debris basin or supplement the basin in excess flow periods. These units are quite large but are quite simple, having substantial capacities and flexibility. Their energy demands are quite modest. Their selection can be largely defined by simple tests with representative effluent. In most instances they are probably not cost competitive with other available alternates but in some instances may prove acceptable. Microstrainers have been described in Section F.

3. The high rate gravity tube will not materially improve the effluent quality of a properly designed debris basin, but its introduction can materially reduce the size of the basin. The introduction is probably not a good economic trade off if space for the debris basin is not limited. However, in constrained areas it may prove a workable choice. If fines are a problem for given site conditions, the tube system appears to have greater potential for fines recovery with a simple coagulant feed system than the ordinary debris basin. Available data for gravity tubes relate almost exclusively to light weight

organic fines. Additional studies are necessary to determine performance characteristics for construction site effluents. The units have potential for unusually large capacity at moderate cost and more specific cost data should be acquired for construction effluents. The energy demand of these units is practically zero. High rate gravity tubes have been described in Section G.

4. A hydrocyclone with an effective capacity is incapable of removing fines. If a debris basin is employed, there is little that the cyclone can contribute to effluent treatment. However, if the discharge is modest and the solids are no finer than fine sand, a cyclone could be effective without a basin. Available information is adequate for selecting units for such use. Energy demands are of concern. The entire processed flow must be supplied with a pumping energy head which may range from 25 to 50 feet. Cyclones have been described in Section H.

5. The swirl concentrator is essentially a compact, circular grit chamber operating by gravitational separation. Under design conditions it will remove all normal mineral solids larger than 350 microns. It will partially recover solids of smaller size but the detention time is too brief to assure high recovery (about 50 percent for fines of 40 micron size). The concentrator may be used to improve the efficiency of a debris basin but cannot supplant the basin for removal of fines. A substantial improvement in recovery of fines is conceivable with the addition of coagulants but no data are available. The device is attractive for its simplicity, portability and low energy head requirements. The swirl concentrator is described in Section H.

6. Centrifuges in general will produce an effluent of better quality than is required for construction site runoff, but with complexities and cost which are difficult to justify for construction site treatment. The characteristics of centrifuges have been briefly described in Section I..

7. Stationary filters of the leaf, disc, and cartridge forms are effective for fine solids but are incapable of handling high rate flows or flows with high concentration. In most cases they require a fairly substantial energy head for operation. They also require a fair amount of manual attendance if fine solids are to be separated. They do not appear well adapted to the construction effluent problem. Stationary filters have been described in Section J.

8. The upflow rapid sand filter is suggested for more detailed study and evaluation. This unit has a capability of operating with a fairly high rate per unit area. In standard practice this is 6 to 12 gpm/sq. ft. It has an especially high capacity for holding solids before requiring backwash. In standard practice this is 10 lbs./sq. ft. It is simpler than a downflow sand unit in that it backwashes with raw water, thus requiring no wash water storage. The unit provides good separation quality (≈ 2 microns) without coagulants and reduction to less than one micron is possible with coagulants. Coagulants, if needed, can be added with a fairly simple "in line" system. Available information relates primarily to a higher level of effluent quality than is probably needed for construction effluents. Studies should be made to determine changes in effluent quality while attempting to operate with coarser granules with higher capacities and less head loss. Energy demands are of concern. The entire flow treated must be supplied with a pumped energy head of 50 feet or

more. These filters lend themselves to effective automation with very little manual care except in the case where coagulant supplies must be maintained. Sand filters have been described in Section J.

9. The rotary vacuum filter has the capability of removing solids with a wide range of size and concentration. It may operate uncoated or coated with filter aid for removal of sizes to less than one micron. Although it has served effectively in a wide variety of filtering problems with acceptable costs, there is reason to question its acceptance for construction site conditions. Although available in highly automated forms, unattended and intermittent operation with variable storm flows would pose some serious problems. The unit also requires substantial energy input for air pumping in vacuum generation and for the pumped return of all filtrate water from the vacuum to disposal. In general, this unit appears to provide a better quality of effluent than is needed, and it also has attendant requirements and a high cost. Rotary vacuum filters have been described in Section J.

10. Electrophoresis at the present state of development does not appear to be a practical solution to the problem of separating solids from construction site runoff. The process was described in Section L.

11. The performance of many types of separation equipment may be dramatically upgraded by the auxiliary use of coagulants and filter aids. However, it is unlikely that construction sites producing widely varying flow conditions and having unattended operations can effectively use coagulants without incurring unacceptable costs. In some cases where objectionable fines must be removed, these auxiliaries may be considered necessary. Coagulants and filter aids were discussed in Section K.

RECOMMENDATIONS

1. For a small construction site where the total discharge is less than about 5 cfs, a debris basin may not be justified. In this case, consideration should be given to the use of on-site techniques for minimizing the erosion (Refs. [C-9], [C-10]). If this is not practical, consideration should be given to processing the effluent with a hydrocyclone, a swirl concentrator or a cyclone supplemented with a sieve bend, depending on soil characteristics. It is doubtful that the total amount of fines would justify the use of an automated filtering system.

2. Further studies should be undertaken to more clearly establish acceptable values for the size and concentration of solids which may remain in the ultimate effluent from a construction site. These values can probably be specified in terms of some standard turbidimeter measurements, but better definition is needed. Establishment of standards should be based on physical tests with a selected set of commonly available clay and silt solids having a range of sizes and electrochemical properties. The possibility of using automatic turbidity meters for control of the treatment process should be investigated.

3. The high rate gravity tube appears to have considerable potential for simple, low energy, and low cost removal of solids down to relatively small sizes and may be used with coagulants for removal of fines. Since available data do not relate to the mineral fines involved in construction sites, it is recommended that tests be made to establish removal characteristics with the same clay and silt solids mentioned in Item 2 above. These solids should be tested individually and in selected mixtures and with and without coagulant. Consultation should be arranged with the manufacturer for recommended installation practices when using the units with debris basins and these should be tested. The tests should involve effluent evaluation with the standard turbidimeter, and maximum practical overload conditions should be established. Based on these tests, operating characteristics should be defined and current cost data and procurement specifications should be assembled.

4. The swirl concentrator in its present state of development is effective in the removal of all mineral solids above 350 microns and partially effective in the removal of finer material down to 40 microns. Because of the relative simplicity, portability, low energy requirements, and low maintenance needs of this unit, it is considered desirable to investigate its potential for further improvement in removal of fines. The inherent low velocity and low shear conditions in the detention chamber suggest the possibility of injecting coagulants in the inlet conduit to promote additional settling in the detention chamber. It is unlikely that recovery will be successful for runoff high in clay fines but may suffice as the complete treatment where runoff is modest and where fines are larger than medium silts.

5. The upflow rapid sand filter or multi-media filter offers good promise for the removal of solids where site conditions produce fines of relatively large concentration. Its relatively high cost and large energy demands are objectionable and it normally produces a better quality effluent than construction site conditions demand. It is recommended that tests be made to see whether costs can be reduced by increasing operating rates, reducing head loss, and reducing effluent quality. This may involve selection and test of an abnormal size of media and this should be done without and with coagulants. Coagulants appear to be much easier to use with these filters then with other equipment. The tests should be made to establish removal characteristics with the same clay and silts mentioned in Item 2 above, and should include evaluations with the standard turbidimeter. The range of operating conditions should establish the maximum practical overload values. The test solids should be tested individually and in selected mixtures. The tests should be done in close cooperation with one or more filter makers. Previous tests have shown that small area filter tests agree well with full-scale filter performance. Based on these tests, operating characteristics should be defined and current cost and procurement specifications should be assembled.

LIST OF REFERENCES

[M-1] Reprinted from Industrial Filtration of Liquids, 1971, by Purchas, D.B., with permission of Leonard Hill Books.

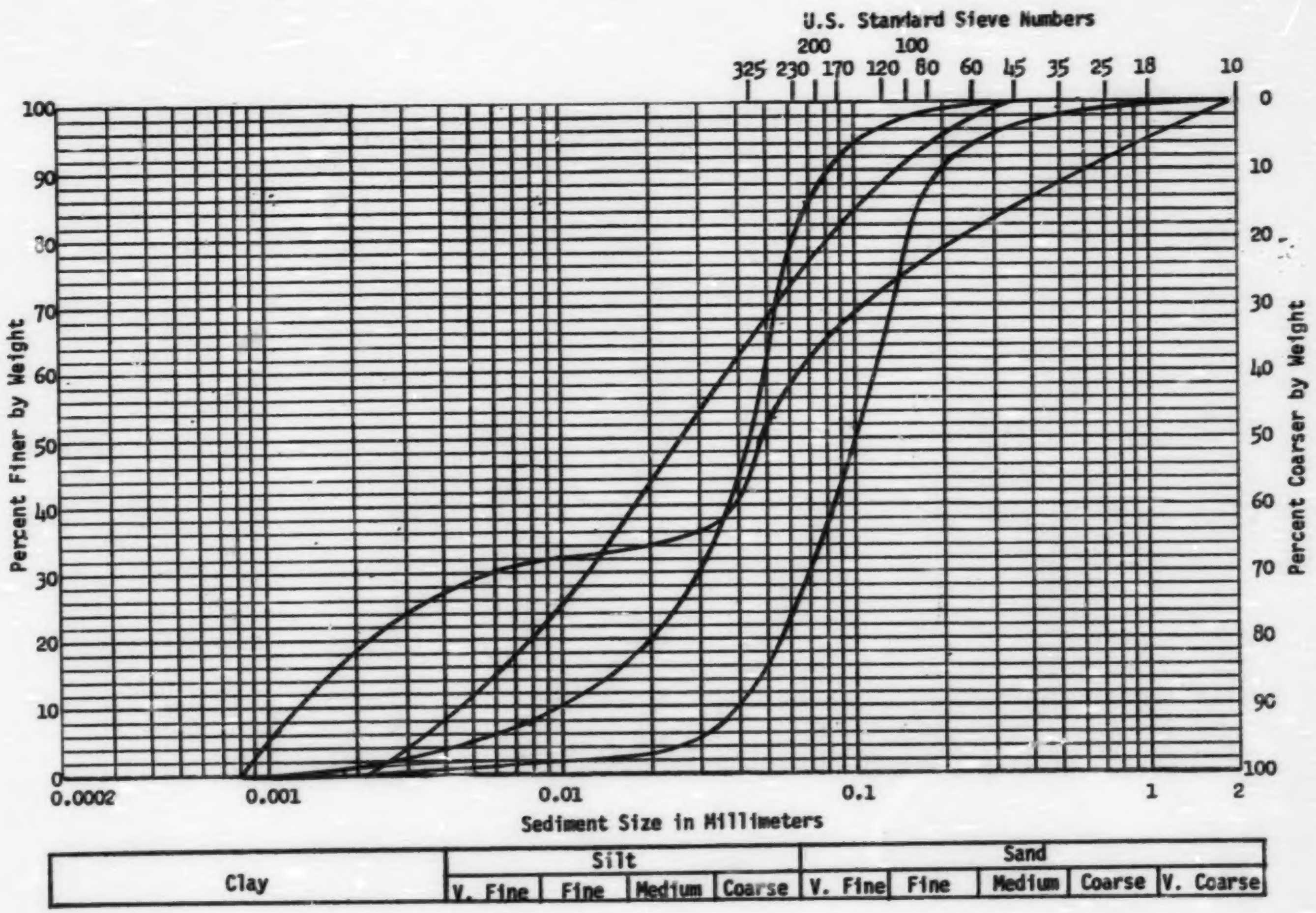


Fig. M-1. Typical examples of construction site soil size analysis curves (size range pertinent to debris basin effluent)

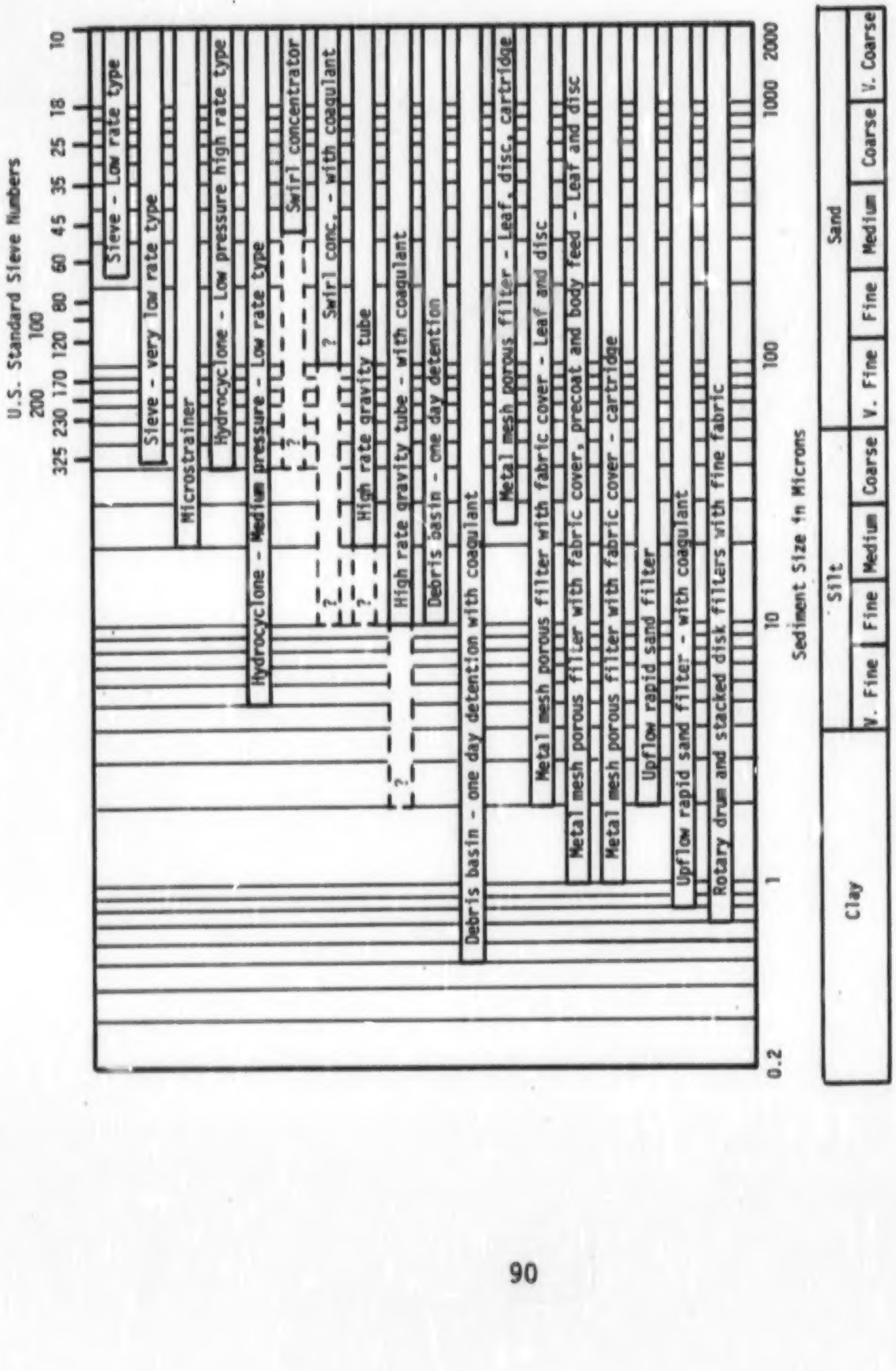


Fig. M-2. Sediment size separation capabilities of treatment facilities for clarification of construction site runoff (all sizes above 2000 microns assumed as intercepted by debris basin)

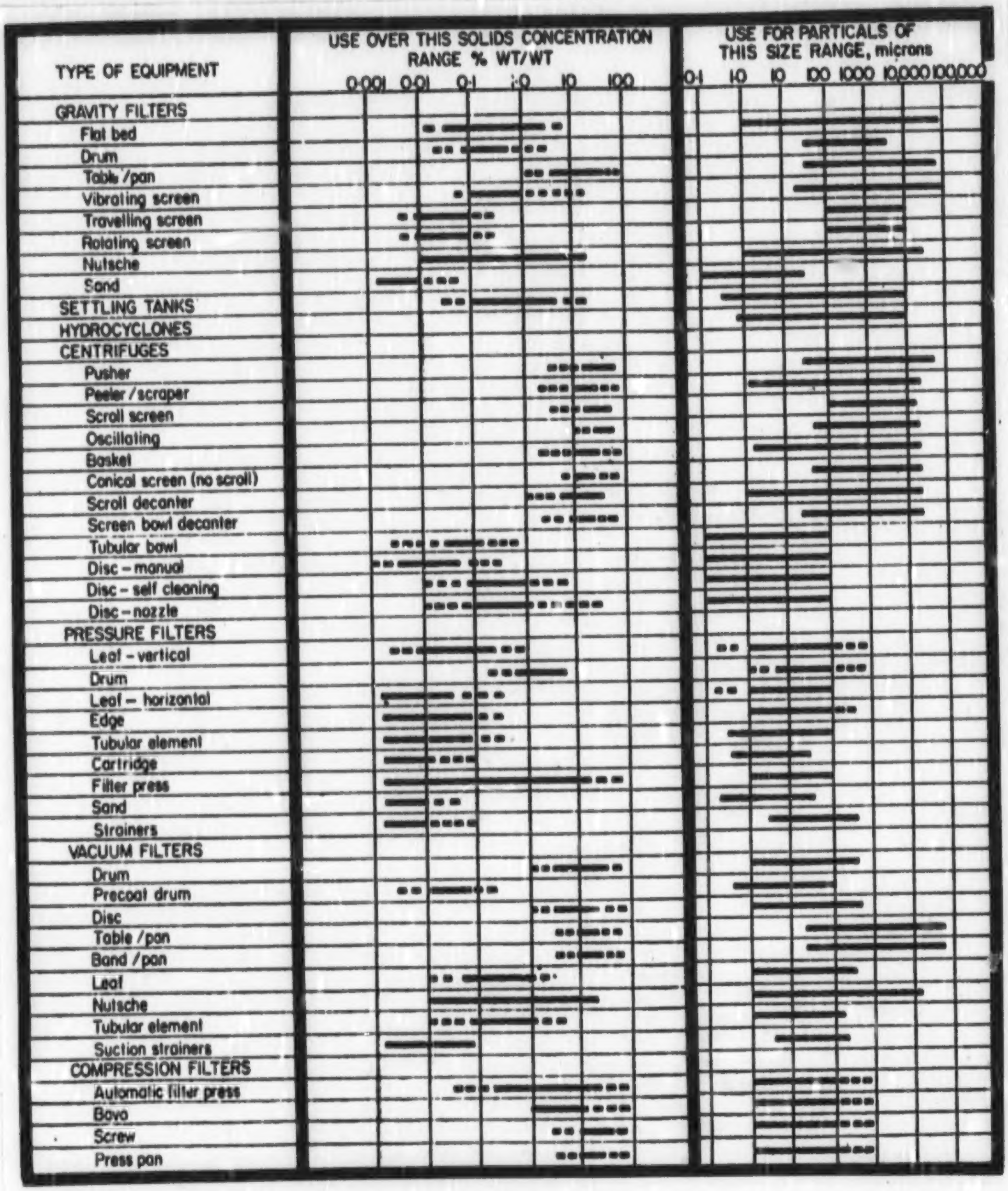


Fig. M-3. A guide to the selection of solids separating equipment as used in industrial clarification problems (After Ref. [M-1])